Climate change impact, individual countries' vulnerability, and the Preparedness of the health systems: how is the world adapting?

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- Nick

Abstract

Background: Climate change is one of the greatest health threats facing humanity. The extent of a country's climate change impacts depends highly on socio-economic vulnerability factors. Health system preparedness mitigates climate change impact, reduces a country's overall vulnerability, and is also under risk itself. The limited research on climate change and health system preparedness often only considers single impacts, countries, or health system segments.

Methods: This cross-sectional ecological study investigates (1) the lagged association between climate change impact and health system preparedness after five years in three time periods at country-level worldwide and (2) the association between capacity to face climate change vulnerability and health system preparedness within the same year. A sub-analysis investigates associations of climate change health vulnerability and health system preparedness. The global climate risk index was a proxy variable for climate change impact, and the ND-gain index substituted the capacity to face climate change vulnerability and health-specific vulnerability. The SPAR score was the proxy for health system preparedness. Crude and adjusted linear regressions explored both relationships.

Results: Climate change impact and health system preparedness showed no associations after five years. Higher capacity to face climate change vulnerability was significantly associated with higher health system preparedness. The sub-analysis of climate change health vulnerability was significant in the crude, not the adjusted analysis.

Conclusion: Health systems seemingly do not adapt to climate change impact even after five years. Simultaneously their reduced capacity to face vulnerability is associated with lower health system preparedness, which is worrying for future impacts.

Keywords: Climate change, climate change impact, climate change vulnerability, health system preparedness, health system resilience, climate adaptation ,

Climate change impact, individual countries' vulnerability, and the preparedness of the health systems: how is the world adapting?

Climate change is the most demanding and urgent global challenge humanity faces in the 21st century. Nations worldwide are impacted in a number of ways including population health (World Health Organization, 2021d). "On the current trajectory, climate change will become the defining narrative of human health", causing millions of deaths if nations do not seriously commit and are able to limit a temperature increase to 1.5 °C (Romanello et al., 2021, p.1621; IPCC, 2018). While climate change as a health threat is a global problem, countries will be affected disproportionately hard depending on numerous factors such as higher impact due to geographical location, vulnerability to climate change, and overall preparedness (Action for Global Health, 2021). Health system preparedness plays a crucial role in mitigating impacts and influencing the degree of vulnerability of a country. To do so, health systems need to include climate change as a core principle in their preparedness plans (Field et al., 2014). If not, health systems will fall subject to climate change, endangering health system progress at a global level of the past 50 years (Watts et al., 2020). The following paragraphs will clarify climate change impact on human health, how climate change vulnerability of countries are determined, and which challenges this poses for health system preparedness in the light of the most recent literature.

Climate change impact

Since 1900 global warming has been leading to an intensification and higher frequency of climate change-induced weather events on a global scale. Likewise, slowly proceeding changes in the environment have been noticed worldwide (IPCC, 2019, 2022). Generally speaking, climate change impact at country level can be understood as adverse effects on human livelihoods, ecosystems, species, environmental activities and functions, economic and social resources and capacities of infrastructure (IPCC, 2022). A number of severe climate change impacts have been identified, adversely affecting human health globally either through weather extremes, through impacts in ecosystems or socio-economic consequences resulting from the two.

Primary impacts of climate change on health

A number of severe climate change impacts have been identified, directly adversely affecting human health, labeled as primary impacts. The majority of primary impacts clearly linked to climate change are an increase in land and ocean weather extremes, droughts, (wild) fires, heavy precipitation, flooding, a growing number of storms and sea level rise (IPCC, 2022).

These impacts affect health in numerous ways. For example, heat waves are closely linked to heat related illnesses and climate sensitive cardiovascular illnesses. Fires and increasing air pollution cause respiratory illnesses, and extreme events can cause trauma and mental health problems as confirmed by several studies and official expert groups (K. L. Ebi et al., 2021; IPCC, 2022; Romanello et al., 2021; Watts et al., 2018; World Health Organization, 2021d). Yet the most severe health outcome is mortality. The most deadly disaster types in the period 1970-2020 were droughts, (650.000 deaths) storms (577.232 deaths), floods (58.700 deaths) and extreme temperatures (55.736 deaths), affecting developing countries particularly hard (according to UN country classification). Ethiopia, for instance, accounted for 400.000 of drought related deaths alone (Zhongming & Wei, 2021).

Most forms of mortality due to extreme weather conditions are well reported, yet the impact of cold temperatures in the form of cold spells is often underreported (Ryti et al., 2016). This is surprising as some studies suggest that cold spells cause even higher mortality: A study conducted in France shows that cold spells were responsible for more deaths in the overall mortality statistics than heat waves (3.9% CI 95% 3.2 to 4.6 compared to 1.2% CI 95% 1.1 to 1.2 (Pascal et al., 2018). Another study analyzed 74,225,200 deaths from 348 locations in 13 (mostly high income) countries and was able to ascribe more deaths to cold spells than to heat (7.29%, CI95% 7.02 to7.49 compared to 0.42%, CI 95% 0.39 to 0.44) (Gasparrini et al., 2015).

Numerous primary impacts of climate change adversely impact human health e.g. in the form of mortality. However, it should be noted that mortality rates have decreased in the past decades despite an increasing frequency of extreme weather events over the period 1970-2020 (Zhongming & Wei, 2021).

Secondary impacts of climate change on human health

Apart from primary impact in the form of extreme weather events, climate change has considerable implications for ecosystems that sustain human livelihood and good health (IPCC, 2022; Romanello et al., 2021). This is evident considering that changes in weather variability and extremes create favorable conditions for the development and spread of waterborne, airborne, foodborne, and vector-borne pathogens (Romanello et al., 2021; World Health Organization, 2021c). Also, the likelihood of zoonose, malnutrition, and prevalence of noncommunicable diseases and mental health problems increases (World Health Organization, 2021d). These impacts can be labeled as secondary impacts as they arise due to primary impacts such as temperature increases.

Especially diseases and health outcomes related to food and water ecosystems are of growing concern. Droughts or floods for example hamper water security in many parts of the world. Negative developments are particularly observed with higher prevalence in low HDI countries (Romanello, et al., 2021). Climate-sensitive waterborne diseases like diarrheal diseases including cholera are growing worldwide after years of decline, due to heavy precipitation and floods contaminating fresh water (IPCC, 2022). In 2020, extreme droughts tormented 19% of the global land surface in any given month, posing a major threat to water and food security, impacting roughly 50% of the world's population (Romanello, et al., 2021; IPCC, 2022). Even in the absence of droughts, the continuous increase in temperatures affects staple crops worldwide, additionally menacing food supplies and food security (Lieber et al., 2022; Romanello et al., 2021). Most severe impacts of general food insecurity were observed in regions within Africa, Asia, Central and South America, Small Island states and the Arctic. Losses in food production within countries are particularly lamentable. They result in reduced quality and diversity of diets, and lead further to malnutrition among vulnerable groups, such as indigineous people, low income households, children, pregnant women and the elderly (IPCC, 2022).

Besides primary impacts causing e.g mortality, severe health threats arise due to secondary impacts of climate change on ecosystems related to food and water safety, for example.

Tertiary, Socio-economic impacts of climate change related to health

Additional far-reaching consequences of primary and secondary climate change impacts are socio-economic impacts, referred to as tertiary impacts. Economic damages arise due to primary and secondary impacts and effects on a macro and micro level. Primary impacts on a macro level result for example in economic losses through demolition of private property and infrastructure (IPCC, 2022). Also, primary and secondary impacts result in loss of income in climate sensitive jobs, agriculture, forestry, energy and tourism on a micro level. As the frequency of extreme weather events has increased over the past 50 years, so have economic losses (period 1970-2020) (Zhongming & Wei, 2021). Economic impact has to be considered with care as less developed countries are impacted considerably less in terms of economic losses on a macro level, but disproportionately hard in terms of fatalities, while the opposite applies to developed countries (according to UN country classification as used by WMO). The disparity of economic impact in comparison to mortality impact becomes clear when looking at Ethiopia and the US between 1970-2020: Ethiopia had 400.000 mortalities, but only 2 billion USD losses, while the US had only 10.000 mortalities but losses of 203 billion USD (Zhongming & Wei, 2021). Although the two countries experienced different types of natural disasters in different years, globally the trend remains: developed countries are affected disproportionately hard by death, but under-represented in economic impact (Zhongming & Wei, 2021). Nevertheless, this does not mean the economic impact in developing countries cannot have far reaching consequences on a micro level in the form of social impact.

Economic climate change impacts might reach enormous dimensions so that people face displacement, poverty or violent conflict as a result of income and property loss (Ebi et al., 2021; Patz et al., 2012). Moreover, lower socio-economic groups are disproportionately affected within a country, (IPCC, 2022; Romanello et al., 2021). Such socio-economic impacts endanger the individual capacity to deal with arising or future health threats, while on a country level, it can lead to a concern of public health (IPCC, 2022; Romanello et al., 2021).

Tertiary socio-economic impacts are observed in a wide spectrum of sectors, on a macro and micro level, posing additional challenges related to public health on health system preparedness and individual health. Figure 1 provides a comprehensive overview of the different forms of impact per world region:

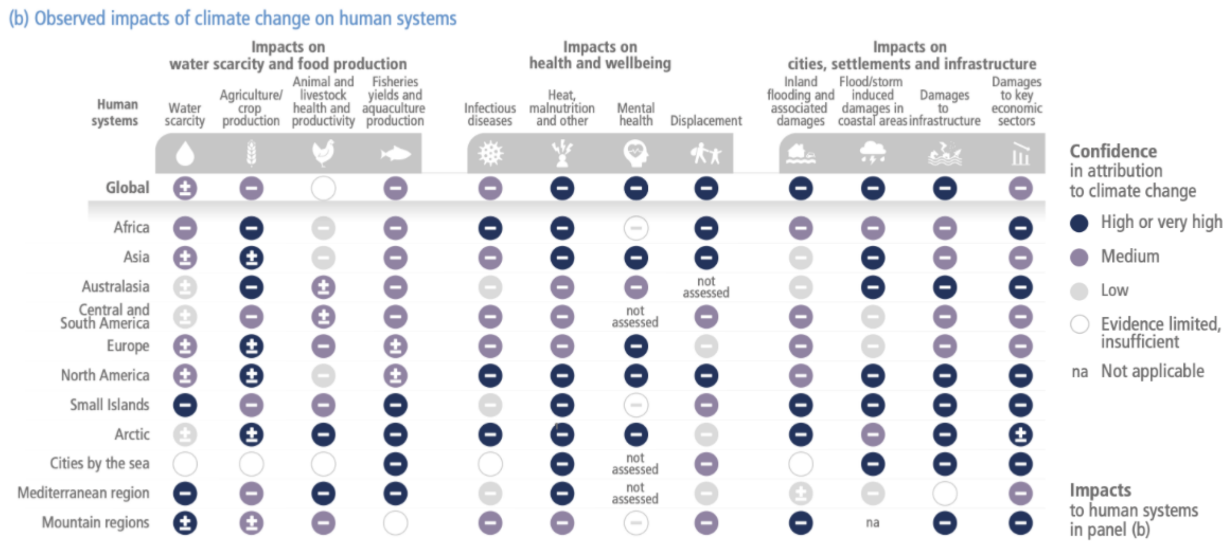

Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For that reason they can be assessed with higher confidence than regional studies, which may often rely on smaller studies that have more limited data. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular.

(a) Climate change has already altered terrestrial, freshwater and ocean ecosystems at global scale, with multiple impacts evident at regional and local scales where there is sufficient literature to make an assessment. Impacts are evident on ecosystem structure, species geographic ranges and timing of seasonal life cycles (phenology) (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.1).

Figure 1. IPCC, 2022, p. 129

Vulnerability to climate change

While climate change is a driver for impact, climate change vulnerability is a characteristic of a country that makes it susceptible to climate change impact. It can be described as "the propensity or predisposition to be adversely affected. It encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" to climate change (IPCC, 2022, p.7).

Climate change vulnerability corresponds to a series of interdependent factors related to human development and ecosystems. Generally speaking, vulnerability is influenced by socio-economic developments such as poverty, low income, extent of political stability, marginalization and potential conflicts. Furthermore, current underlying factors of vulnerability are connected to historically based inequities and dependencies resulting from colonialism. Besides, socio-economic development, access to basic resources and key infrastructures such as water and sanitation, health services, private and public transportation, communication and energy supply, are equally essential. (IPCC, 2022).

Next to these human based factors, ecosystems are also vulnerable to climate change and have a reciprocal relationship with human health and livelihoods. High climate change vulnerability in an ecosystem will exacerbate potential impact on climate sensitive livelihoods such as precipitation related agricultural or fishing communities, but also give room to water and food related global health emergencies as described above (IPCC, 2022).

The combination of these mediating factors for humans and ecosystems leave 3.3 to 3.6 billion people in highly vulnerable conditions worldwide. A striking majority of these people live in West-, Central- and East Africa, South Asia, Central and South America, Small Island States and the Arctic (IPCC, 2022).

Vulnerability to climate change depends on socio-economic developments and ecosystem dependance. Vulnerabilities are expected to rise, expand and shift further as a consequence of increasing migration and urbanization, often related to climate change. Simultaneously, inequalities will aggravate these trends, if standards in related fields, such as health systems, do not account for climate change as a core principle and serious health threat (Ebi, 2013; Field et al., 2014; IPCC, 2022).

Climate change and health system implications:

Health System preparedness is one influencing factor for the degree of vulnerability to climate change of a country and its ability to mitigate climate change impacts (Ebi et al., 2018). Preparedness is defined by the UN as "the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions" and this is also the underlying WHO definition for preparedness (World Health Organization, n.d., par. 1). This thesis uses the term health system preparedness, however, some papers refer to health system resilience which is considered unanimous.

Generally speaking, the health system incorporates a certain degree of preparedness to alleviate unpredictable and short-lasting health emergencies, called shocks. It also features certain preparedness capacities to resist continued hardship resulting due to circumstances like demographic change in a country, called health stress. Continued strain on the health system can ideally increase health system capacities due to slow adaptation. Yet too high levels of stress eventually decrease capacities, including emergency preparedness (Berry et al., 2018). Contrastingly, a high-level or an accumulation of health shocks might diminish the overall health system preparedness (Kaji et al., 2008).

Since levels of health shocks and stress are linked to climate change, health systems must incorporate climate change as a central principle in emergency preparedness and health system capacity (Field et al., 2014; World Health Organization, 2015). Inevitably, higher frequencies of natural disasters, disease outbreaks, or famines will increase health shocks. Simultaneously malnutrition and heat stress are likely to intensify health stress. Aggravatingly, non-climatic and climatic events will increasingly intersect to an indistinguishable effect and exacerbate their impact on health systems, which is why they should incorporate climate change in their preparedness plans (Smith et al., 2014).

The theory of climate change health system preparedness

Several internationally coordinated efforts have aimed at providing guidance on how to implement climate change in health system preparedness. However, only since the Paris agreement in 2015 has the topic gained recognition and importance. The most comprehensive framework was published by the WHO in the same year as an operational framework for building health system preparedness for climate change (World Health Organization, 2015).

The WHO framework includes five action points critical to ensuring climate change health systems preparedness. **(1)** First, a scientific basis for policies needs to be established by continuously assessing climate change related vulnerabilities and exploring adaptation possibilities. **(2)** Resulting from the scientific assessments, implementation on policy level in the form of national adaptation plans can follow. **(3)** Also, healthcare facilities should stay accessible, affordable and adapt with changing climate conditions, while incorporating sustainable and environmentally friendly care. **(4)** To realize (1) to (3), nations will need to (re-)allocate sufficient funds and resources towards health system preparedness. This is especially challenging in lower and middle income countries due to financial gaps. **(5)** Lastly, health systems need to create space for collaboration and synergies with other related fields that are usually independent from one another. Hence, fields prone to impact or high in their vulnerability like water management, food security, energy and agriculture, need to be considered and financed to develop all-embracing adaptation strategies that include climate change at the core (World Health Organization, 2015).

Most recently, the COP26 special report on climate change and health has been published by the WHO, building on the 2015 framework by additionally addressing governance and policy makers on a larger scale. Here, the WHO gives far reaching advice for an overarching approach including promotion of transformative and adaptive efforts for example related to health, food, and ecological systems, city planning, post Covid-19 recovery, and financing strategies (World Health Organization, 2021d)

Reports and frameworks addressing a broader international context and frameworks providing a holistic concept of health system preparedness for climate change are of great significance, yet these need to be implementable at national and subnational level in an individual context, which might not always be possible (Shaw, 2016).

The reality of climate change health system preparedness

Internationally, progress and challenges can both be seen when developing climate change health system preparedness according to the 2015 Framework.

(1) On the brighter side of things, over two thirds (67%) of countries in the WHO health and climate change global survey (total n=95) indicate they assess vulnerability and adaptive capacity linked to climate change in the health system (World Health Organization, 2021a). However, assessments used for implementations often focus on past impacts, rather than accounting for future vulnerabilities (Berry et al., 2018).

(2) Moreover, 77% stated to have national health and climate change strategies under development or implemented, (World Health Organization, 2021a). Yet, implementation is not unanimous for effectiveness. According to Romanello et al. (2021) 63% of countries investigated (total n=166) were identified as unprepared for climate change related emergency responses due to too low quality of implemented emergency frameworks.

(3) The WHO reports relatively low adaptation levels of health system facilities concerning climate change related health impacts, as 39% (total n= 78) report to have surveillance systems for vector-borne diseases, 32% for water-borne diseases (total n=78), 35% for airborne and respiratory diseases (total n=65), 21% for zoonoses (total n=66), 13% for mental and psychosocial health (total n=47), and 11% for malnutrition and foodborne diseases (World Health Organization, 2021a). Hence the adaptation of health facilities is low for many countries, but more importantly, so is the access. Especially regions with high climate change vulnerability are identified to be often the regions with the lowest health coverage and access (Salas & Jha, 2019)

(4) Lack of financial and human resources have been identified as one of the main barriers for action points (1) - (3), especially in low income countries. Still, only 28% of low and lower-middle income countries receive international funds to foster climate change preparedness in their health systems (World Health Organization, 2021a). Furthermore, due to lack of financial resources, vulnerability assessments are conducted to varying standards, are often not considered t in decision-making and have limited effectiveness due to limited adaptation (Anderson, 2009; Berry et al., 2018; K. L. Ebi et al., 2018; Keim, 2011)

(5) Fragmentation of authorities concerning climate change impact has been identified as another barrier, as local health departments lack responsibility (Hamstead et al., 2020). Therefore, it is important to note that almost 75% of countries have established coordination mechanisms between different stakeholders in the fields of water safety, sanitation and hygiene, pollution and meteorological services (World Health Organization, 2021a). Nonetheless, the improvements appear to be rather small scale, and further stakeholders should be included regarding for example urban planning and energy transition as well as high levels of international cooperation, as advocated in the COP 26 report (Jessel et al., 2019; Kent & Thompson, 2014; Romanello et al., 2021; World Health Organization, 2021d).

Limited progress is evident, but incremental improvements may not be sufficient. Additionally poorly performed assessments might create a false sense of confidence that future impacts can be managed while future impacts are likely to be beyond health shocks and health stresses experienced to date (Berry et al., 2018; Ebi et al., 2018). Thus, it is questionable if health system preparedness adapts to climate change impacts.

Aims and Objectives

Despite the topic's high relevance, research falls behind when investigating the interplay of climate change and health systems preparedness. A meta-analysis of Biddle et al. (2020) shows that only 11% of empirical studies on health system preparedness (total n=71) focus on climate change. Furthermore, most studies investigate climate change impact on a country level, a specific type of impact or spotlight on one particular part of health systems, but not on health system preparedness as a whole. Also, clear definitions of climate change were often lacking or varied widely (Biddle et al., 2020).

Hence the aim of this paper is to contribute to a better and more clearly defined understanding of the associations between climate change and health system preparedness at the global level. To our knowledge this is the first study scrutinizing progress in health system preparedness after climate change impact and the capacity to face climate change vulnerability

in relation to health system preparedness as a whole. Specifically, the objectives of this paper are to asses:

1. The lagged association between climate change impact of the periods 2008-2012, 2009-2013, 2010-2014 and health system preparedness in 2017, 2018, 2019 (5 years later) at country level, worldwide, using an ecological study design.
2. The cross sectional association between capacity to face climate change vulnerability and health system preparedness in the year 2019

To account for climate change impact the Global Climate Risk Index was used, which reports a country's exposure associated to climate change-induced weather loss events that have a socio-economic impact in terms of direct loss or fatalities (Eckstein et al., 2019). As a proxy variable for capacity to face climate change vulnerability, the ND-Gain Index is applied. It measures a country's vulnerability to climate change in combination with its readiness to improve adaptive capacities by considering six life-supporting factors, including a sub indicator climate change health vulnerability (Chen et al., 2015). Lastly, the SPAR-score (State Parties Self-Assessment Annual Report) - a self-reported indicator based on a country's implementation of WHO-agreed international health regulations was chosen to estimate the overall health system preparedness (World Health Organization, 2005).

We hypothesize that (1) countries that have experienced higher climate change impact will show higher levels of health system preparedness after five years due to adaptation measures and that adaptation increases from 2017 to 2019. Whereas we expect that (2) a country's high capacity to face climate change vulnerability will be associated with high health system preparedness. Additionally, we anticipate to identify a (3) negative association between a country's climate change health vulnerability and health system preparedness. Lastly, we conjecture (4) differences in the associations listed above according to income levels of countries.

Methodology

Data collection

To conduct the cross-sectional ecological analysis all data was gathered from publicly available databases at country level, allowing comparison at group level rather than individual level. Two exposure (independent) variables were considered at country level, worldwide: climate change impact, and a country's capacity to face climate change vulnerability. One outcome (dependent) variable was used: health system preparedness.

For climate change impact data from the time period 2008-2014 was divided into three 5 year averages (2008-2012, 2009-2013, 2010-2014). For the capacity to face climate change vulnerability data from the year 2019 was used, while for health system preparedness data from 2017, 2018 and 2019 was used. The data of the confounder variables is timely identical to the used exposure variables. All variables are described in detail below.

Exposure variables

Climate change impact

To identify the extent to which countries have been impacted by climate change the Global Climate Risk Index (GCRI) by Germanwatch retrieved from the United Nations Office for the Coordination of Humanitarian Affairs and the Germanwatch website was used (Eckstein et al., 2019; United Nations Office for the Coordination of Humanitarian Affairs, 2018). The metadata for the indicators is retrieved from the Munich Re NatCatSERVICE database, being one of the most validated and elaborative datasets for climate change impact (Eckstein et al., 2019; Munich Re & NatCatSERVICE, n.d.). Despite the name Global Climate "Risk" Index, this index accounts for climate change induced weather-related loss events, (e.g floods, heat waves etc.) that had a socio-economic impact on a country in the form of direct loss or fatalities. Hence, the indicator asses primary and tertiary climate change impacts on a macro level, but not secondary impacts The estimated impact is assessed through four indicators: (1) total number of deaths, (2) number of deaths per 100 000 inhabitants, (3) sum of losses in US$ in purchasing power parity (PPP) and (4) losses per unit of gross domestic product (GDP). The indicator is a ranking and is calculated as the average ranking of a country in each category according to the following weighting: death toll, ⅙; deaths per 100 000 inhabitants, ⅓; absolute losses in PPP, ⅙; losses per GDP unit, ⅓.. This results in a ranking from 1 to approximately 109 in 2008-2012 and

2009-2013, and a ranking from 1 to 117 in 2010-2014. The higher the ranking of a country, the lower the climate change impact a country has witnessed (Germanwatch, 2019).

Capacity to face climate change vulnerability

As an indicator for the capacity to face climate change vulnerability the ND-Gain Index, developed by Notre Dame University was used. This measures the vulnerability of a country to climate disruptions as well as its readiness for the implementation of adaptation capacities.

The index is therefore composed of two major components assessing vulnerability and readiness for adaptive actions through 45 indicators received from public databases of reliable and authoritative organizations (Chen et al., 2015). A comprehensive overview is provided in figure 2.

The vulnerability component consists of 36 indicators equally split across 6 life-supporting sectors: food, water, health, ecosystem services, human habitat, and infrastructure. Each life-supporting sector is further divided into three sub-components, assessing the *exposure, sensitivity*, and *adaptive capacity* of a sector. *Exposure* forecasts impact for the coming decades from a biophysical perspective, disregarding socio-economic contexts. The *sensitivity* subcomponent measures the dependency of a country on a sector that might be affected by climate change-induced disasters, and the share of a country's population that is vulnerable to those disasters. Further, the *adaptive capacity* depends on the social resources available within a sector that would allow for sustainable solutions for adaptation, and the ability to replace unsustainable practices with new ones (Chen et al., 2015).

As a sub-analysis for the sub-indicator climate change health vulnerability was performed, it will be presented briefly: *Exposure* of climate change health vulnerability is based upon the projected change of deaths from climate change-induced diseases and the projected change of length of transmission season of vector-borne diseases. *Sensitivity* of climate change health vulnerability accounts for slum populations of a country and the dependency on external resources for health systems. The *adaptive capacity* component relates to medical staff, in particular physicians, nurses, and midwives, and access to improved sanitation facilities (Chen et al., 2015).

The readiness component of the ND-Gain Index consists of three sub-components: *economic-, governance-,* and *social* readiness that influence the vulnerability components. *Economic* readiness quantifies the conditions for businesses to mobilize investments that would allow for increased adaptation and reduced sensitivity of a country, resulting in reduced overall vulnerability. *Governance* readiness refers to social and institutional stability, influencing investment risks. A receptive public service combined with a highly stable and secure political system in a country can reduce investment risks for adaptive capacities and increase security for growth for investors, especially from outside the country. Lastly, *social readiness* captures social structures that will allow for efficient and equitable use of adaptive investments. These social structures include the education system from primary to tertiary level, fairness of the rule of law as well as sufficient development of information and communication technologies (Chen et al., 2015).

To calculate one overall ND-gain score, vulnerability and readiness are added according to the following formula: ND-Gain score = (readiness score - vulnerability score +1) x 50. Vulnerability and readiness scores range both from 0 to 1. After entering into the formula, the ND-gain score is ranging from 0-100, the higher the score, the lower the vulnerability and the higher the readiness for adaptive actions in a country (Chen et al., 2015).

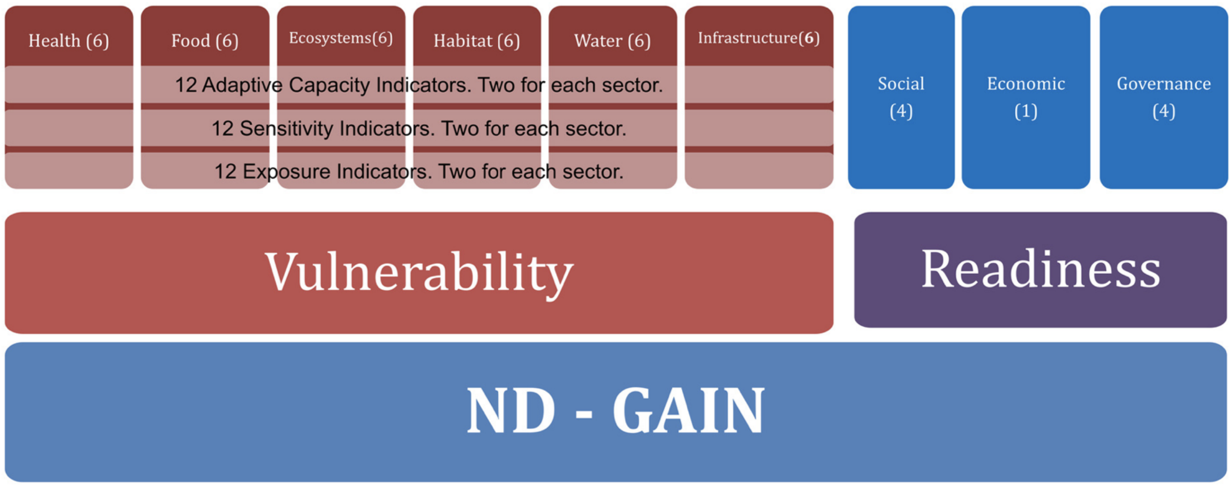

Figure 2. (Chen et al., 2015, p.6)

Outcome variable

To assess the health system preparedness of a country, the "State Self-Assessment Annual Report" (SPAR) was used. SPAR is a tool to track progress on healthcare system preparedness and capacity building according to the international health regulations (IHR), provided publicly by the WHO (World Health Organization, 2005). The IHR are a set of rules as well as a framework aimed at increasing health system capacity to prepare for public health risks and emergencies. Each country is obliged to report about the progress of their IHR to the World Health Assembly and have to therefore closely monitor the developments in their country (World Health Organization, 2016b). The SPAR allows to track the progress of the IHR thanks to 24 indicators across 13 IHR capacities that are important to detect, assess, notify, report, and respond to health emergencies of various kinds (World Health Organization, 2005).

Climate change is not explicitly considered in the evaluations, however, climate change is influencing the different capacity dimensions, and countries might react to climate change impact in the different areas of preparedness. The 13 capacities are (C1) legislation and finance, (C2)

IHR coordination and NFP functions, (C3) zoonotic events and the human-animal interface, (C4) food safety, (C5) laboratory, (C6) surveillance, (C7) human resources, (C8) national health emergency framework, (C9) health service provision, (C10) risk communication, (C12) chemical events (World Health Organization, 2018).

Each capacity contains one to three indicators. The indicactor level is expressed in percent along a 1 to 5 scale and then converted to percent (e.g ⅗*100=60%). The average of the indicators of one capacity then build the capacity score (e.g (⅗*100+⅘*100)/2=70%). In a last step all 13 capacity scores result in an average SPAR score expressed in percent for the country (World Health Organization, 2018).

Confounding variables

To account for possible factors influencing potential associations between exposure and outcome, development and progress measuring variables of a country have been taken into consideration. The Human Development Index (HDI) data was extracted from the United Nations development programs report website in order to consider progress in essential areas of human development in socioe-conomic terms (UNDP, 2020). Additionally, the Global Peace Index, published by Vision of Humanity and using data from the Institute for Economics and Peace, recon the social safety and security of a country and moreover assess the level of conflict and militarisation (Vision of Humanity, 2021). This variable allows to minimize the influence of war related events that might have a major impact on the crude association. Furthermore, the general government gross debt as percent of GDP, retrieved from the International Monetary Fund, has been considered as an indicator for the extent of sustainable finance of a country, impacting government decisions and implementations of regulations (International Monetary Fund, 2021). Lastly, the share of the population above 65 years of age has been derived from Our

World in Data and accounts for the age structure of a country which might cloud the association between the exposure and outcome variable. This might be due to higher vulnerability and impact of climate change on the elderly and higher preparedness of the health system due to adaptation to demographic change (Ritchie & Roser, 2019; IPCC, 2022).

Statistical analysis

The descriptive analyses were performed using Qgis 3.8 to locate the geographical climate change impact, countries capacities to face climate change vulnerability and health system preparedness. Besides, the program Tableau was used for creating scatterplots of the exposure and outcome variables while color coding the different income levels of countries according to the World Bank (n.d.).

Beforehand, all variables were checked for normality and log transformed were needed. Missing values were deleted and not included in the analyses. Additionally, correlation matrices were created to check for linear relationships between the confounding variables. The following crude and fully adjusted associations were tested using linear regression models (figure 3):

(1) First, the association between climate change impact for the time periods 2008-2012, 2009-2013 and 2010-2014 and health system preparedness 5 years later were tested (2017, 2018, 2019).

(2) Second, the association between the capacity to face climate change vulnerability and health system preparedness in 2019 was tested.

(3) A sub-comparison for the sub indicator climate change health vulnerability was conducted for the same time period, to identify potential additional associations between health specific vulnerability of a country and its health system preparedness.

(4) In a last step, interaction of the associations (1), (2) and (3) with income levels of the countries were tested. Results were described by income level where the test showed significance.

The adjusted multivariable regressions included the Human Development Index, Global Peace Index, the general government gross debt as percent of GDP and the share of population above 65 as confounding variables for the years of the exposure variables (climate change impact and climate change vulnerability and readiness for adaptive actions). A p-value of < 0.05 was considered statistically significant. The linear regressions were performed in STATA 16 SE.

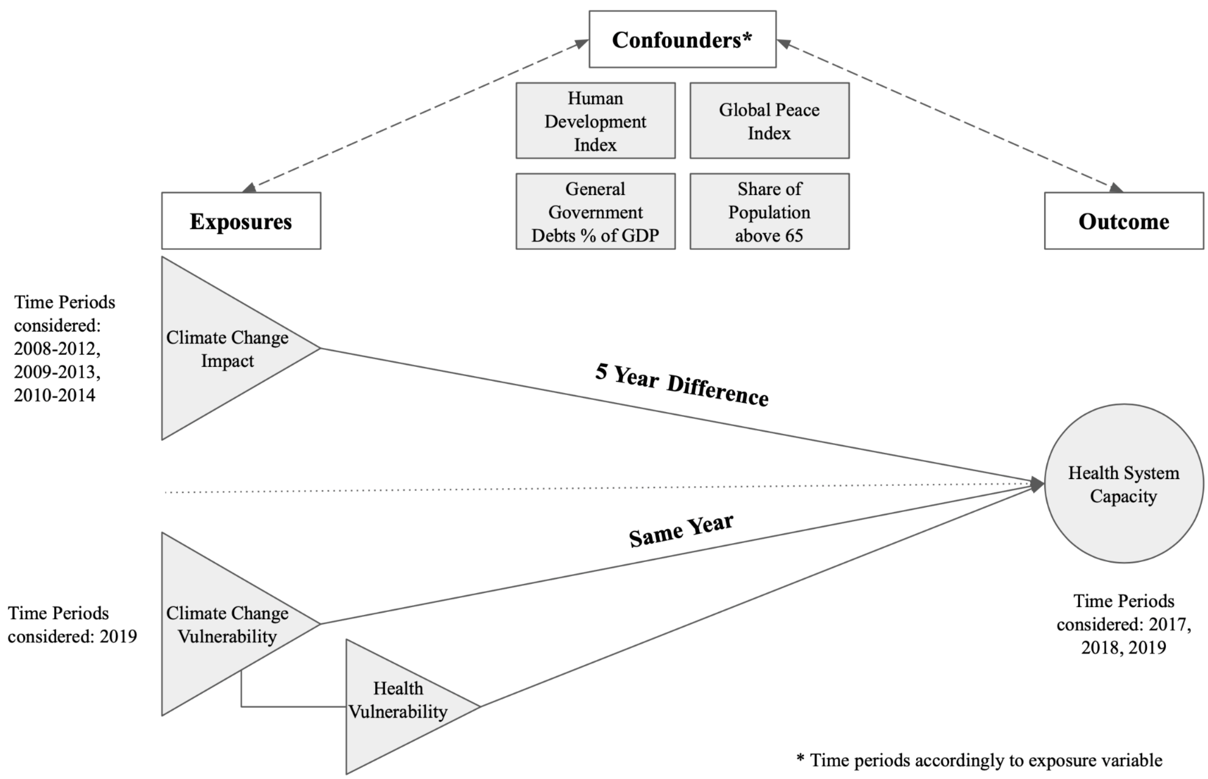

Figure 3. Conceptual model of the statistical analyses

Results

Descriptive statistics results

Climate change impact

Climate change impact slightly decreased over the three time periods as the mean ranking of impact increased: 2008-2012 mean 71.33 (SD 22.30); 2009-2013 mean 73.27 (SD 22.41); 2010-2014 mean 76.02 (SD 24.13). Furthermore, the climate change impact increased for most impacted countries over the time periods, while it decreased for the least impacted countries. The Philippines was the most impacted country in 2008-2012 with a ranking of just 13.73 as well as in 2009-2013 with a ranking of 12.07. Pakistan was the most impacted with a rank of 10.97 between 2010-2014. The highest ranks and therefore least impacted in 2008-2012 with 108.84 were Bahrain, Djibouti, Equatorial Guinea, Eritrea, Hong Kong, Jordan, Kiribati, Libya, Qatar, Seychelles, Timor and Turkmenistan. Just slightly less impacted and with a higher ranking of 108.96 in 2009-2013 were Equatorial Guinea, Hong Kong, Kiribati, Qatar, Timor, Turkmenistan, Uzbekistan. 2010-2014 had the largest increase in the ranking with 117.67 for Micronesia, Palau, San Marino, Tuvalu as least impacted countries. The overall distribution of climate change impact is well visible in figure 4 for the period 2010-2014. Periods 2008-2012 and 2009-2013 show similarly clear distributions as shown in the appendix.

Dividing countries per income level shows that across all three time periods high income countries have been the least impacted followed by low income countries, then upper middle income countries and lower middle income countries as can be derived from table 1.

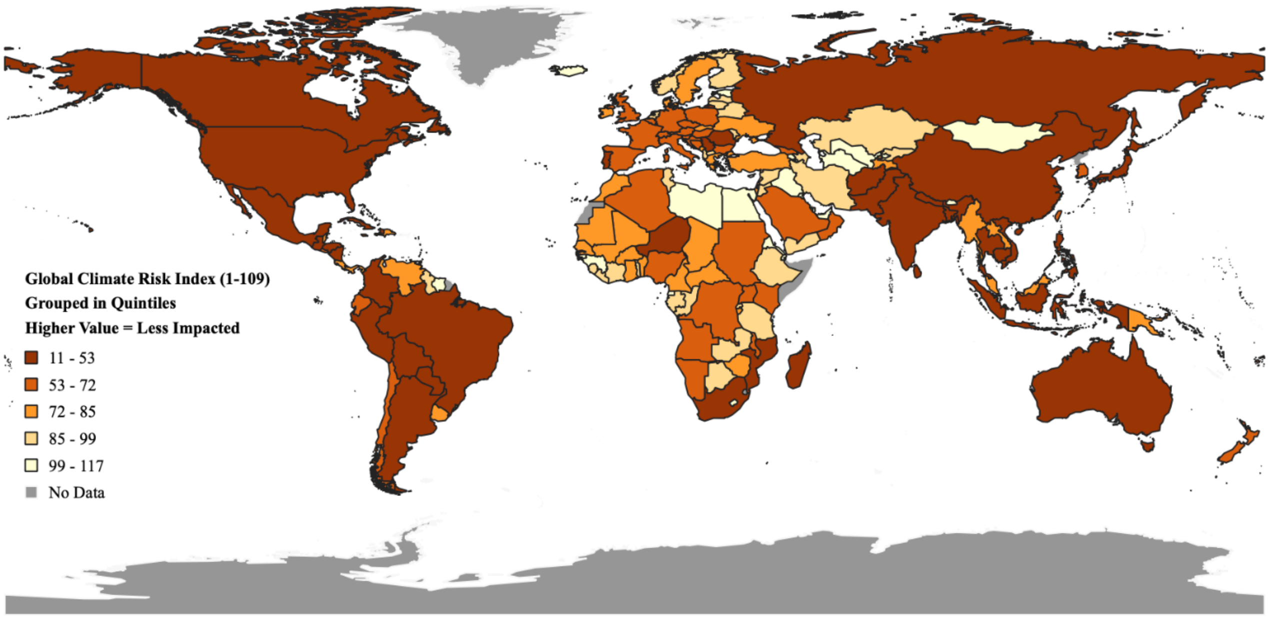

Figure 4. World Map of climate change impact 2010-2014 according to Global Climate Risk Index.

Capacity to face climate change vulnerability

The capacity to face climate change vulnerability in 2019 has an overall mean of 49.65 (SD 11.09) with Chad having the lowest capacity to face climate change vulnerability with a score of 28.40, while Norway scores the highest with 76.22. It should be noted that 9 of the 10 countries with the lowest capacity to face climate change vulnerability are located in Sub-Saharan Africa, while 8 out of 10 countries with the highest capacity to face climate change vulnerability are located in Europe.

For the sub-indicator climate change health vulnerability in 2019, the mean is 0.42 (SD 0.20) with Somalia having the highest climate change health vulnerability score of 0.85, being most vulnerable and Japan the lowest with 0.11, being the least vulnerable. 8 of the 10 bottom countries concerning climate change health vulnerability are located in Sub-Saharan Africa, while 9 out of 10 of the top counties are located in Europe again. For both variables a clearer clustering in specific regions can be seen as displayed in figure 5 and 6.

Regarding income levels, the capacity to face climate change vulnerability increases with higher income levels as the mean score for capacity to face climate change vulnerability is the lowest among low income countries, mean 35.70 (SD 3.77). A similar trend is apparent for climate change health vulnerability with the highest mean of .71 (SD .10) in the low-income category and thus the highest climate change health vulnerability, and the lowest mean 0.21 (SD 0.09) in the high income category and therefore the lowest climate change health vulnerability.

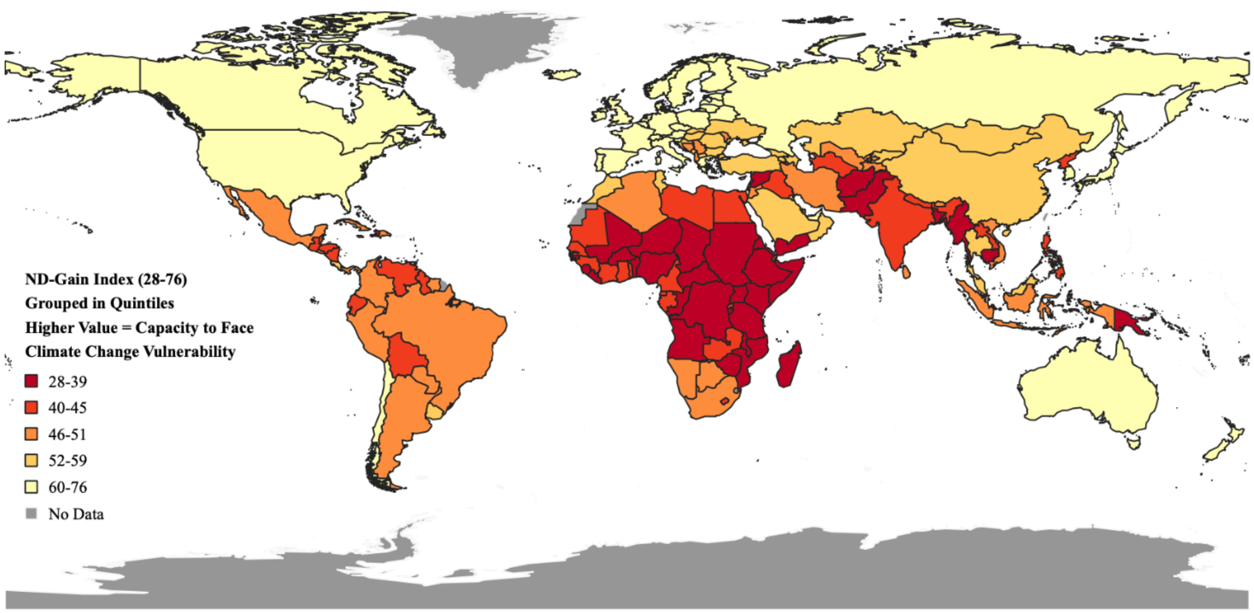

Figure 5. World map of capacity to face climate change vulnerability according to the ND Gain Index in 2019.

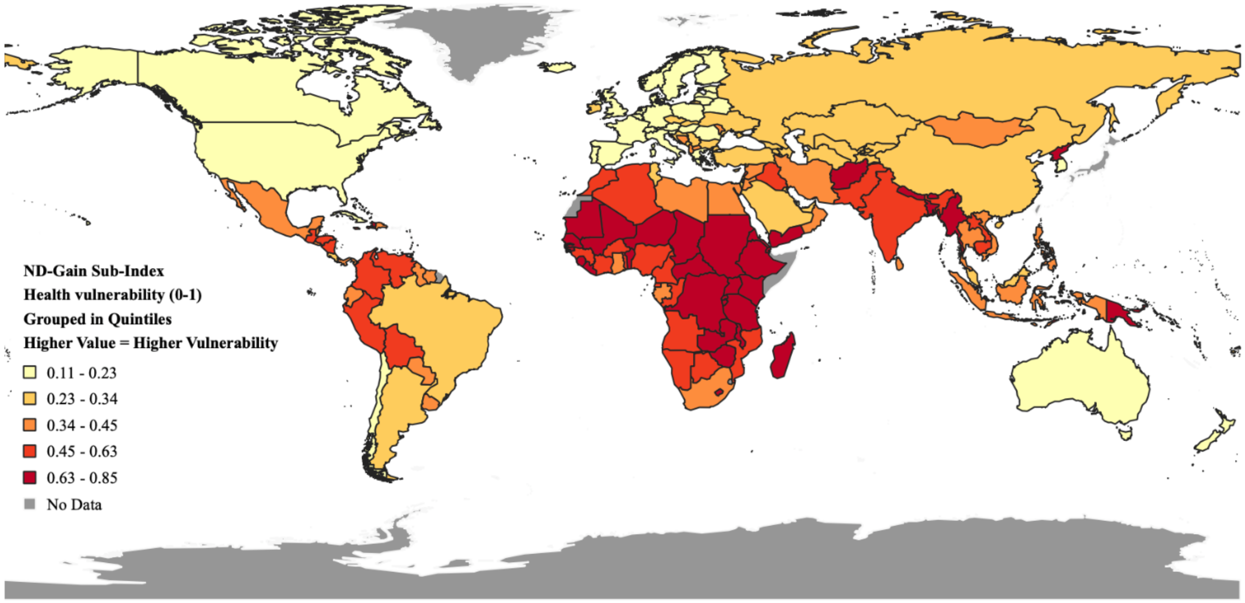

Figure 6. World map of climate change health vulnerability according to the health sub-index of the ND-Gain Index in 2019.

Health system preparedness

The overall mean for health system preparedness varies within the years observed as can be seen in table 1. The highest health system preparedness in 2017 were present in Australia, US, China, Canada, Japan with a score of 100 and lowest in Sao Tome and Principe with 16. In 2018 Cuba, Oman and Russia had the highest health system preparedness (100), while Central Africa had the lowest (13). In 2019 Canada and Russia had again the highest health system preparedness with a score of 99 and Central Africa again the lowest with 17.

Health system preparedness showed relatively clearer regional differences as depicted in Figure 6 for 2019, especially for low health system preparedness. For example 9 out of 10 countries with the lowest health system preparedness are located in Sub-Saharan Africa. The years 2017 and 2018 can be found in the appendix.

Comparing health system preparedness by income group, the mean of health system preparedness shows an increase per income group in all time periods as displayed in table 1. A detailed list with the descriptive statistics can be found in table 1 including confounding variables.

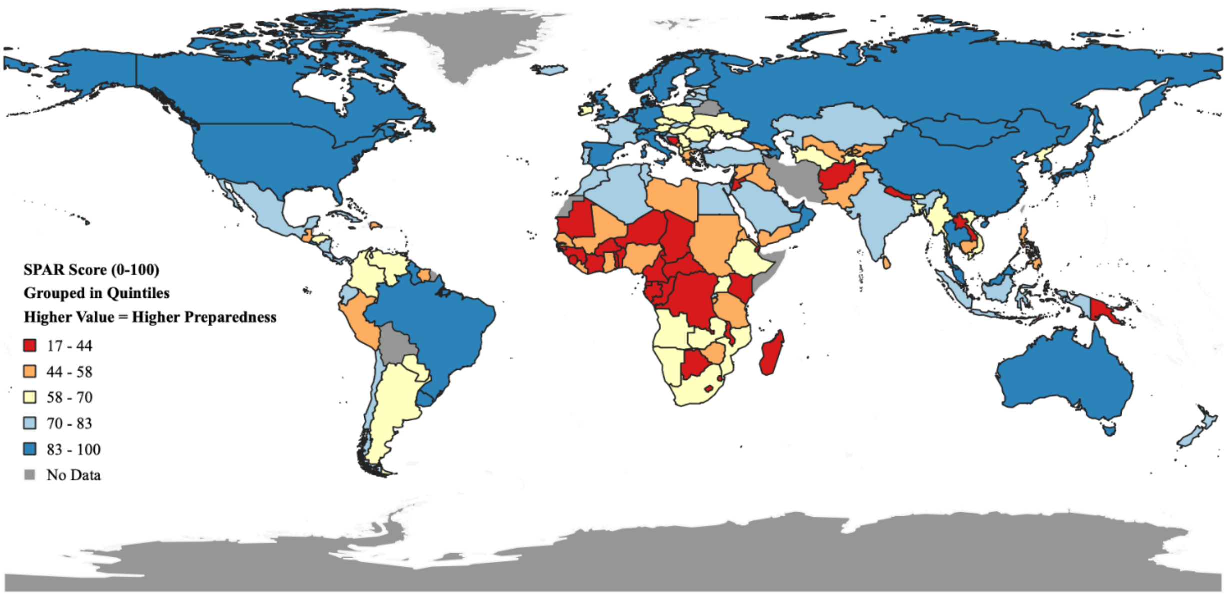

Figure 7. World map of health system preparedness 2019 according to SPAR scores

Table 1.

Descriptive statistics of all variables and clustered in income groups for countries

Variables	Overall		Low income		Lower middle income		Upper middle income		High income	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Climate change impact 08-12	185	71.33 (22.30)	25	72.41 (19.56)	52	67.14 (23.81)	54	70.98 (23.82)	54	75.22 (20.16)
Climate change impact 09-13	183	73.27 (22.41)	24	74.56 (21.35)	52	70.43 (25.39)	53	73.28 (21.84)	54	75.42 (20.60)
Climate change impact 10-14	189	76.02 (24.13)	25	76.03 (23.39)	52	73.59 (27.24)	55	75.03 (24.02)	56	79.29 (21.59)
Capacity to face climate change vulnerability 19	181	49.65 (11.09)	26	35.70 (3.77)	52	42.92 (5.14)	51	50.27 (5.57)	52	62.8 (7.05)
Climate change health vulnerability 19	190	.42 (.20)	26	.71 (.10)	53	.55 (.14)	54	.38 (.10)	57	.21 (.09)
Health care system preparedness 17	162	71.47 (20.90)	27	53.59 (16.52)	45	65.82 (21.91)	40	73.15 (18.25)	50	84.86 (14.28)
Health care system preparedness 18	177	60.66 (20.99)	27	42.93 (14.82)	49	50.98 (17.44)	51	65.00 (17.99)	50	75.30 (18.22)

Health care system preparedness 19	172	63.42 (20.32)	26	44.92 (13.58)	46	52.91 (17.49)	48	66.13 (17.35)	52	79.48 (14.24)
Share of population above 65 in 08-12	188	11.60 (7.57)	27	5.72 (1.58)	55	7.10 (2.74)	51	11.76 (5.20)	55	18.83 (8.58)
Share of population above 65 in 09-13	188	11.74 (7.76)	27	5.71 (1.65)	55	7.12 (2.76)	51	11.87 (5.29)	55	19.21 (8.78)
Share of population above 65 in 10-14	188	11.91 (7.98)	27	5.71 (1.72)	55	7.14 (2.80)	51	12.00 (5.40)	55	19.65 (8.99)
Share of population above 65 in 19	187	13.81 (9.75)	26	5.65 (1.67)	55	7.76 (3.40)	51	14.02 (6.75)	55	23.54 (10.33)
General government gross debt as % of GDP 08-12	192	45.07 (34.76)	25	44.96 (38.49)	55	36.78 (19.44)	53	39.06 (27.48)	59	58.25 (45.42)
General government gross debt as % of GDP 09-13	192	46.01 (34.62)	25	41.72 (34.11)	55	37.30 (20.07)	53	40.42 (27.34)	59	60.97 (45.65)
General government gross debt as % of GDP 10-14	192	46.59 (34.48)	25	40.27 (31.37)	55	37.76 (20.78)	53	41.26 (27.22)	59	62.29 (45.54)
General government gross	191	57.82 (37.46)	24	40.27 (31.37)	55	53.89 (26.89)	53	54.88 (37.35)	59	62.21 (42.30)

debt as % of GDP 19										
Global Peace Index 08-12	162	2.07 (.43)	27	2.40 (.44)	44	2.19 (.28)	45	2.15 (.36)	46	1.67 (.31)
Global Peace Index 09-13	162	2.07 (.43)	27	2.42 (.45)	44	2.19 (.28)	45	2.16 (.35)	46	1.67 (.31)
Global Peace Index 10-14	162	2.07 (.43)	27	2.43 (.44)	44	2.18(.28)	45	2.15 (.34)	46	1.67 (.31)
Global Peace Index 19	162	2.07 (.49)	27	2.54 (.55)	44	2.15 (.31)	45	2.14 (.41)	46	1.65 (.34)
Human Development Index 08-12	188	.67 (.16)	25	.44 (.077)	55	.59 (.09)	52	.73 (.05)	56	.86 (.05)
Human Development Index 09-13	188	.69 (.16)	25	.44 (.067)	55	.59 (.08)	52	.73 (.05)	56	.86 (.05)
Human Development Index 10-14	188	.70 (.15)	25	.45 (.06)	55	.60 (.08)	52	.74 (.05)	56	.87 (.05)
Human Development Index 19	193	.71 (.18)	26	.46 (.10)	55	.63 (.08)	54	.74 (.12)	58	.86 (.17)

Statistical analysis results

For the adjusted analyses the correlation matrices for confounding variables showed no high correlations (higher than 0.8).

(1) Climate change impact and health system preparedness

No association was found between (1) climate change impact and health system preparedness over the three time periods considered in the linear regression in both crude and adjusted models, meaning neither increase nor decrease in health system preparedness are present 5 years after climate change impact.The individual results for the crude and adjusted analyses between climate change impact (2008-2012, 2009-2013, 2010-2014) and health systems preparedness (2017, 2018, 2019) are displayed in table 2. Additionally, the crude association of climate change impact and health system preparedness for 2019 is plotted in figure 8, while 2017 and 2018 can be found in the appendix. The picture is similarly scattered.

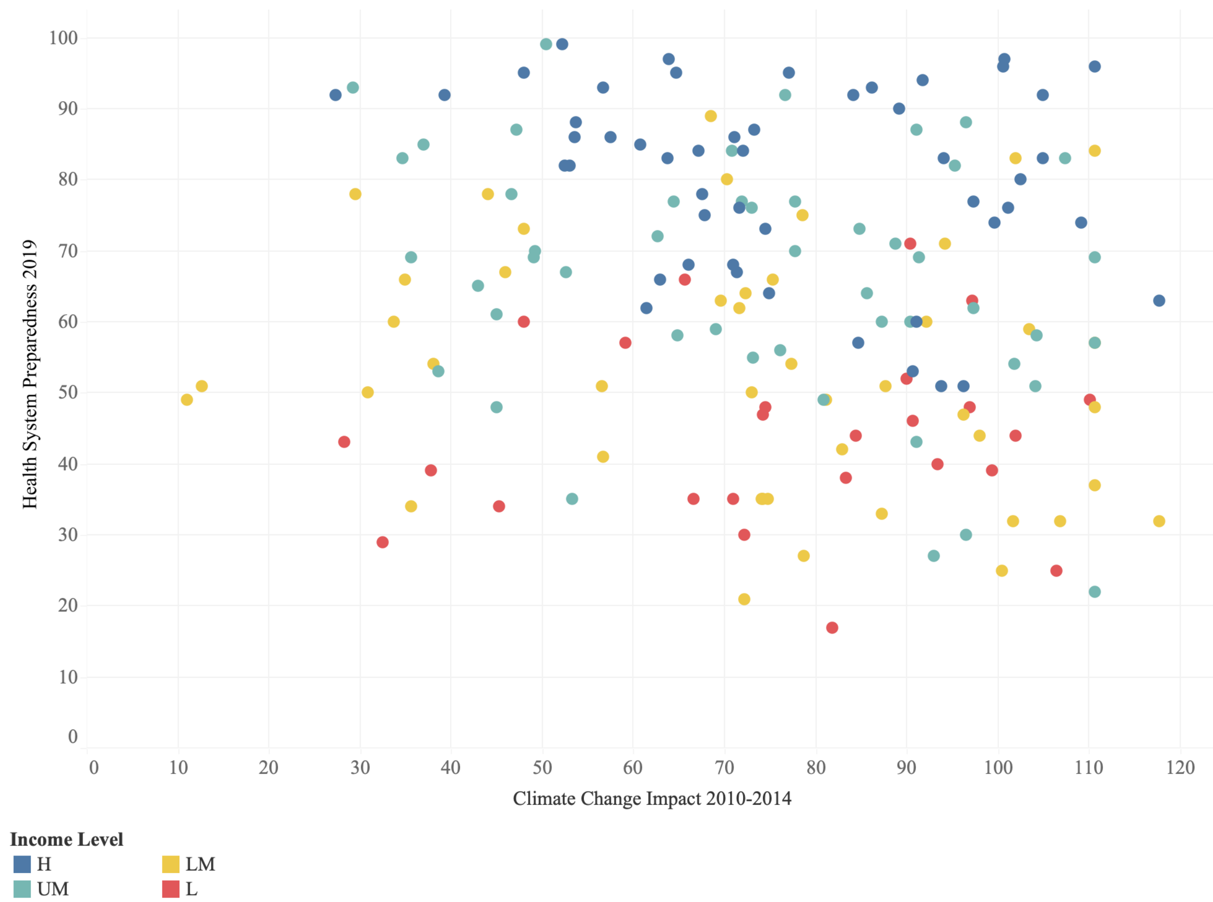

Figure 8. Scatterplot of the association between health system preparedness in 2019 and climate change impact in 2010-2014, color coded by income groups.

(2) Capacity to face climate change vulnerability and health system preparedness

Analysis (2) shows that a country's capacity to face climate change vulnerability is significantly positively correlated with its health system preparedness in the year 2019 (β 1.33; 95% CI 1.14, 1.52). Furthermore, after adjusting for confounders the association remains significant, however, the β coefficient drops from 1.33 to 1.06 (β 1.06; 95% CI .48, 1.65). This means that for each increase in the score for capacity to face climate change vulnerability, the health system preparedness score increases by 33 points in the crude and 6 points in the adjusted analysis. The results for analysis (2) are presented in table 3 and the crude association is depicted in figure 7 as a scatterplot, underlining the clear positive association of the crude model.

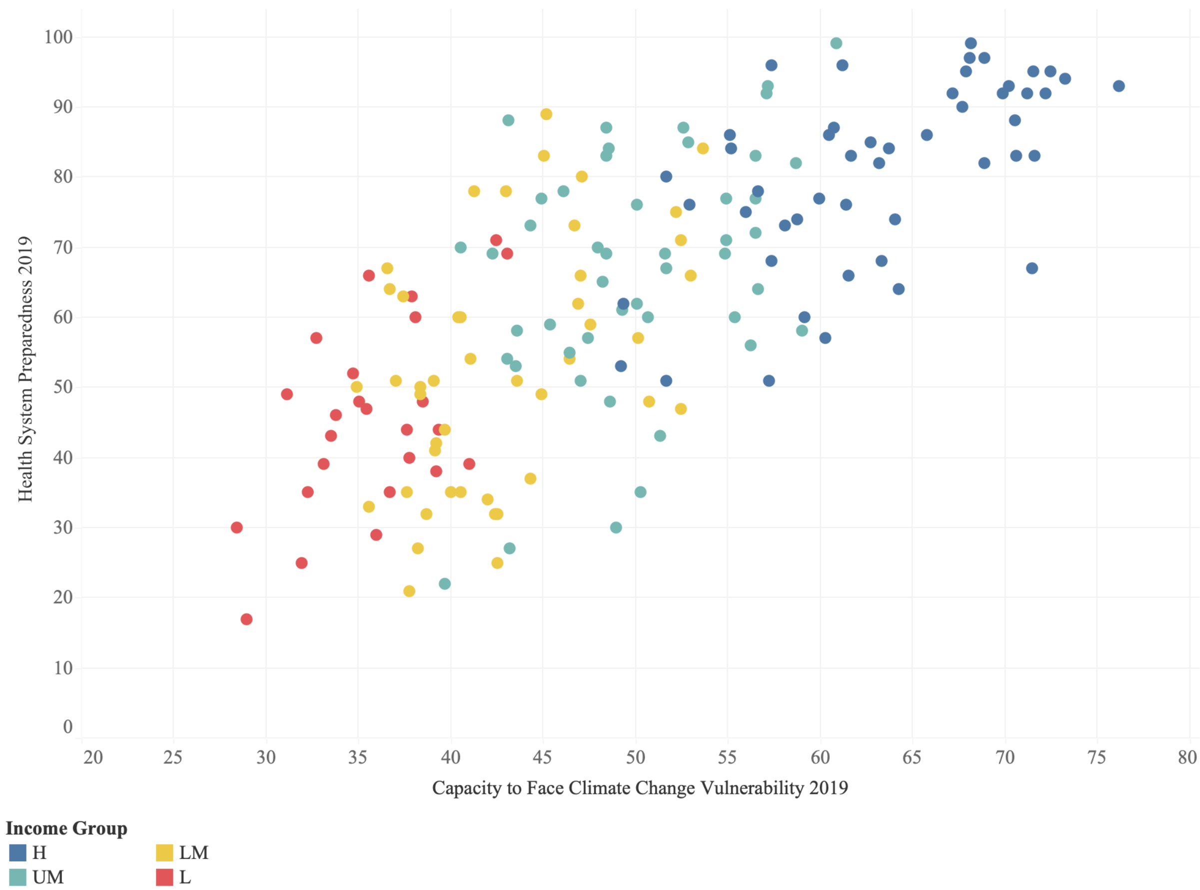

Figure 9. Scatterplot of the association between the capacity to face climate change vulnerability and health system preparedness in 2019, color coded by income groups.

(3) Climate change health vulnerability and health system preparedness

The crude analysis assessing the association between (3) a country's climate change health vulnerability and health system preparedness showed a significant negative association in the crude model (β -67.82; 95% CI -78.60, -57.04). This means for every 0.1 increase in climate change health vulnerability on the 0 to 1 scale, the health system preparedness score lowers by 6.78 points. However, the association is lost in the adjusted multivariable analysis (β -11.77; 95% CI -41.20, 17.66). The results for analysis (3) are presented in table 3, and figure 8 represents the crude association of a country's climate change health vulnerability and health system preparedness.

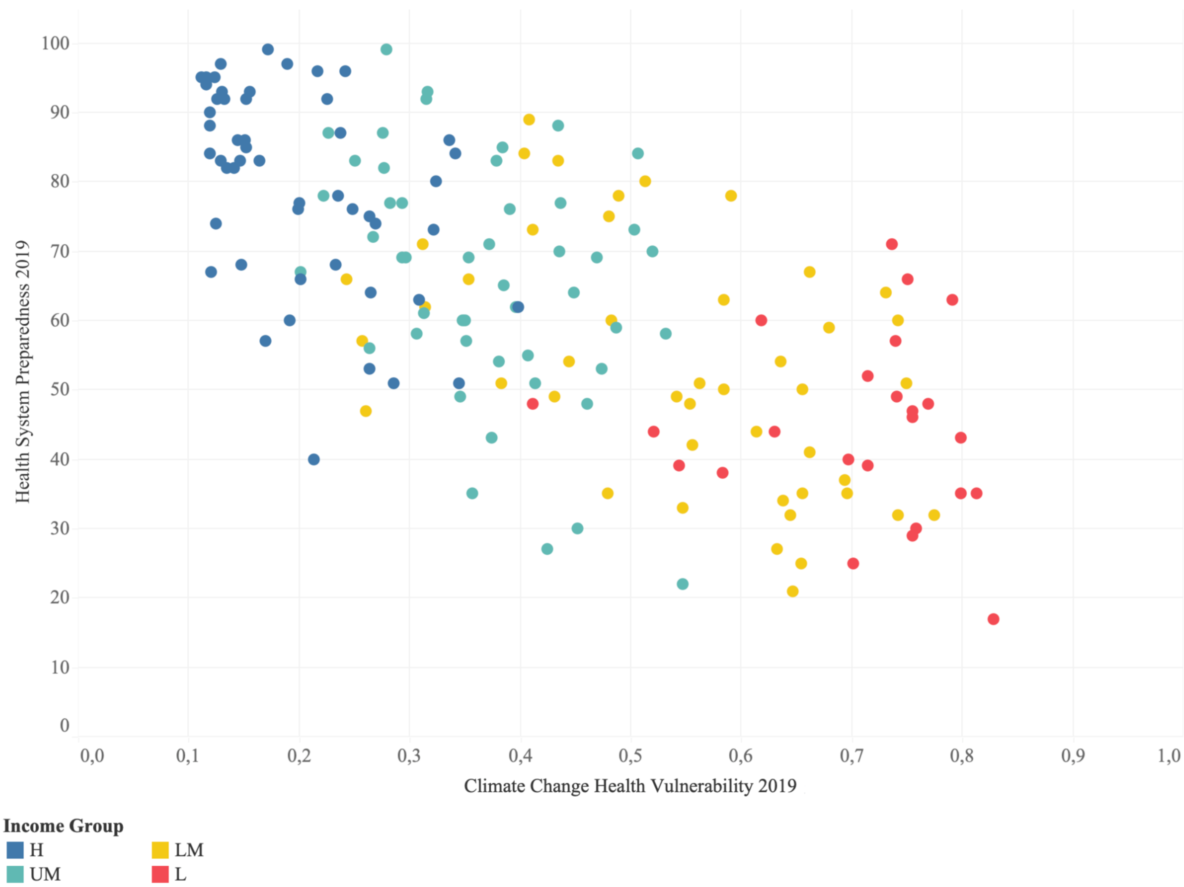

Figure 9. Scatterplot of the association between climate change health vulnerability and health system preparedness in 2019, color coded by income groups.

(4) Associations per income levels

When testing for interaction of the associations (1) to (3), no interaction was detected by income levels: (1) climate change impact 2008-2012 and health system preparedness: 2017 (p= 0.17); 2009-2013 and 2018 (p=0.23); 2010-2014 and 2019 (p=0.38). Also no interaction was detected between (2) capacity to face climate change vulnerability and health system preparedness per income level in 2019 (p=0.56). Lastly no association was present between (3) climate change health vulnerability and health system preparedness per income level in 2019 (p=0.21).

Table 2.

Crude and adjusted linear regression climate change Impact (2008-2012, 2009-2013, 2010-2014) and health system preparedness (2017, 2018, 2019)

Outcome: Health system preparedness 2017, 2018, 2019

Variables	**Crude linear regression**			**Adjusted linear regressions**		
	N	Crude β coefficient	95%CI	N	β coefficient	95%CI
Outcome	Health system preparedness 2017					
Climate change impact 2008-2012	153	-.14	-.28 to .005	133	-.1200997	-.25 to .01
Share of population above 65 in 08-12	**154**	**1.12**	**.72 to 1.52**	**133**	**-.67**	**-1.23 to -.11**
General government gross debt as % of GDP 08-12	156	0.10	-.003 to .20	133	.08	-.02 to .17
Global Peace Index 08-12	**140**	**-16.62**	**-24.27 to -8.96**	133	.19	-8.20 to 8.58
Human Development Index 08-12	**157**	**74.76**	**58.68 to 90.85**	**133**	**97.54**	**72.29 to 122.80**
Outcome	Health system preparedness 2018					
Climate change impact 2009-2013	167	-.09	-.24 to .06	144	-.01	-.11 to .10

Share of population above 65 in 09-13	**169**	**1.52**	**1.17 to 1.88**	144	-.13	-.58 to .32
General government gross debt as % of GDP 09-13	172	.076	-.02 to .18	144	.02	-.06 to .10
Global Peace Index 09-13	**151**	**-15.34**	**-22.96 to -7.73**	**144**	**7.24**	**.73 to 13.75**
Human Development Index 09-13	**171**	**95.78**	**81.63 to 109.94**		**113.54**	**92.49 to 134.5**
Outcome	Health system preparedness 2019					
Climate change impact 2010-2014	168	-.12	-.25 to .01	150	-.06	-.16 to .03
Share of population above 65 in 10-14	**167**	**1.34**	**1.02 to 1.66**	150	-.34	-.78 to .09
General government gross debt as % of GDP 10-14	**167**	**.14**	**.05 to .23**	150	.04	-.03 to .12
Global Peace Index 10-14	**155**	**-18.00**	**-25.14 to -10.86**	150	.98	-5.56 to 7.52
Human Development Index 10-14	**171**	**94.64**	**81.32 to 107.96**	**150**	**108.15**	**87.29 to 129.01**

Table 3.

Crude and Adjusted linear regression climate change vulnerability and readiness for adaptive action and Health System Preparedness (2019); climate change health vulnerability and Health System Preparedness (2019)

Outcome: Health system preparedness in 2019

Variables	**Crude linear regression**			**Adjusted linear regressions**		
	N	Crude β Coefficient	95%CI	N	β Coefficient	95%CI
Outcome	Health system preparedness 2019					
Capacity to face climate change vulnerability 19	**166**	**1.33**	**1.14 to 1.52**	**147**	**1.06**	**.48 to 1.65**
Share of population above 65 in 19	**166**	**1.15**	**.88to 1.41**	**147**	**-.38**	**-.73 to -.03**
General government gross debt as % of GDP 19	166	.07	-.01 to .16	**147**	**.06**	**.004 to .12**
Global Peace Index 19	**155**	**-14.79**	**-20.95 to -8.63**	**147**	**7.87**	**2.01 to 13.73**
Human Development Index 19	**172**	**85.40**	**71.67 to 99.13**	**147**	**57.06**	**18.79 to 95.32**

Outcome	Health system preparedness 2019					
Climate change health vulnerability 19	-	-	-	147	-11.77	-41.20 to 17.66
Share of population above 65 in 19	-	-	-	147	-.20	-.56 to .15
General government gross debt as % of GDP 19	-	-	-	147	.05	-.01 to .11
Global Peace Index 19	-	-	-	147	4.49	-1.29 to 10.27
Human Development Index 19	-	-	-	**147**	**100.96**	**60.80 to 141.12**

Discussion

Climate change impact poses a significant risk to health system preparedness and climate change adaptation (World Health Organization, 2021d). Yet this study suggests that health systems do not increase in their preparedness after climate change impact in any investigated period. This indicates that health system preparedness does not adapt or include climate change in its development over time, leaving them unprepared for further climate change impact. Simultaneously, this study shows that lower capacity to face climate change vulnerability is associated with lower health system preparedness, suggesting that a country's vulnerability characteristics are also reflected in the health system preparedness and that efforts are needed to decrease its vulnerability and increase adaptation of health system preparedness. This paper adds to the growing literature on the relationship of climate change and health systems. Apparently it is the first to scrutinize adaptations of health system preparedness as a whole post hoc climate change impact, and to assess climate change vulnerability and health system preparedness.

Climate change impact and health system preparedness

Although, according to Berry et al. (2018), most implementations concerning climate change in health system preparedness are done retrospectively and based on impact assessment, none of the periods (2008-2012, 2009-2013, 2010-2014) of climate change impact is associated with increases in health system preparedness after 5 years in 2017, 2018 or 2019 respectively. Climate change impact was measured according to weather related loss events in economic and fatality terms using the GCRI. Considering that health system preparedness is assessed through the SPAR indicator which measures implementation levels of the international health regulations for emergency preparedness, this points towards either a disregard of climate change as a health emergency, or towards barriers to improving preparedness in line with the international health regulations.

It is problematic that health systems do not adapt to climate change impact, given that the results advocate that climate change impact is slightly increasing over the time periods and, more importantly, that the extent of impact increases for the most impacted countries over time as supported by the IPCC (2022). As this study only considers three time periods, these trends should be evaluated further.

Literature suggests that low prioritization of climate change as a health topic and other barriers prevent implementation of health system preparedness considering climate change. First of all, one of the main barriers to implementing climate change response in health system preparedness remains financial resource constraints. (World Health Organization, 2021a). Financial constraints might either prevent any implementation or high quality of implementations, as the vast majority of countries that implemented an emergency response framework of too low quality to be effective (Romanello et al., 2021). Even when disregarding financial hardship within a country, only <1% of international climate adaptation finances are allocated to health adaptation and "there is a significant global adaptation gap in health, as efforts are well below the level required to minimize negative health outcomes" (Neufeldt et al., 2018, p.XIV).

Besides, climate change is not always recognized or prioritized as a health concern, but might be regarded as a separate and mostly environmental issue in some countries (Ebi et al., 2021). This leads to the problem that health systems are not incorporating climate change as a core component of the health system, or that stakeholders such as health ministries simply lack the authoritative power to tackle climate change related challenges (Doubleday et al., 2020; Field et al., 2014; Hamstead et al., 2020).

The positive example of Cambodia illustrates how international efforts can help overcome financial constraints, but also how progress might be jeopardized due to low prioritization of climate change as a serious threat in other sectors. Cambodia has been exposed to increased frequency and intensity of extreme weather events such as heat waves, floods and droughts in recent decades. Additionally, the country has low financial resources, high inequalities, and endangered ecosystems (World Health Organization, 2021b). Since 2013, Cambodia has been paving the way for policy implementations that put climate change at the core of the health system. The most important implementation is the National Strategic Plan for Climate Change Adaptation and Disaster Risk Reduction in the Health Sector 2019–2023 (World Health Organization, 2021b). This implementation includes enlarging facility capacities and numbers, climate change related training of professionals as well as surveillance and early warning systems for multiple climate sensitive diseases such as dengue fever (McIver et al., 2016). As Cambodia is considered a low income country, foreign investments are needed to promote equitable financing structures, which are realized by the Global Environment Facility (GEF) (GEF, 2021). Furthermore, the United Nations Development Programme (UNDP) supports Cambodia in the implementation of programs and facility building, while the WHO supervises and educates on climate resilient health system building (UNDP, 2021; World Health Organization, 2021b). These combined efforts have led to an increase in data availability for climate change and health, reduced complexity on administrative levels and assessment as well as identification of 20 climate vulnerable healthcare facilities (World Health Organization, 2021b). On the one hand this shows how climate change can be successfully incorporated in health system preparedness, on the other hand, Cambodia is also an example of how incremental improvements alone cannot mitigate climate change impact if related fields do not take climate change seriously as well. The Mekong river causes severe floods every year and is identified as one of the major climate sensitive health threats. Yet deforestation and new damming projects along the river have been ongoing, and are expected to cause changes in flood dynamics, disrupting several eco and food systems that could cause losses of rice crops and fishery, hence endangering livelihoods and food security (The World Bank Group & Asian Development Bank, 2021).

Cambodia is a lower-middle income country, which, according to the results of this study, is the most impacted income group. These results are in conflict with the literature as it is proposed that low-income countries are the most impacted country (IPCC, 2022). Our results in fact identify low income countries as the second least impacted income level, after high-income groups. This might be due to the measurement of climate change impact as the GCRI accounts for fatalities and economic losses only. Economic losses tend to be the highest in high income countries, while the opposite is true for fatalities (Zhongming & Wei, 2021). Consequently, a regression to the mean might be observed from both income groups.

Capacity to face climate change vulnerability and health system preparedness

In line with the literature, lower capacity to face climate change vulnerability was present among lower income countries and increased per income group, but unsustainable practices such as those seen in Cambodia will increase a country's vulnerability to climate change in any income group (IPCC, 2022). The capacity to face climate change vulnerability in this study was measured using the NDGain index, which combines a country's vulnerability to climate change depending on 6 life supporting sectors, with a country's capacity to implement adaptive actions through governance, economic, and social readiness.

As identified in this research, lower capacity to face climate change vulnerability was associated with lower health system preparedness in 2019. Health system preparedness and the capacity to face climate change vulnerability stand in a reciprocal relationship. The capacity to face climate change vulnerability is determined by socio-economic and ecosystem related factors that will impose or alter additional stress on health system preparedness, as the literature shows (World Health Organization, 2015). Simultaneously, health system preparedness influences capacity to face climate change vulnerability to a certain extent as well (IPCC, 2022). Thus the drop of the β coefficient from 1.33 to 1.06 once adjusted for confounders, can be explained due to strong influences of confounding variables. They account for 27 points of the decreases in the SPAR index (1.33-.106=1.27). This indicates that other factors, besides the capacities to face climate change vulnerability according to the ND-gain index, seem to be associated with a decline in health system preparedness as well. Still, the adjusted association also shows that the capacity to face climate change vulnerability alone is clearly correlated with a decline in health system preparedness. One possible explanation for this might be that a low capacity to face climate change vulnerability poses continuous stress on the health system. Ebi et al. (2018) points out that, while adequate levels of health stress are beneficial for increasing health system preparedness, too high levels will eventually result in a declining health system preparedness level.

The example of the Central African Republic (CAR) as the 2nd lowest in capacity to face climate change vulnerability and the country with the lowest health system preparedness can underline the reciprocal relationship and the overall negative association between climate change vulnerability and health system preparedness. CAR scores low in the capacity to face climate change vulnerability due to various factors, such as recurring violent conflicts, fraudulent and poor governance, weak institutional capacities, high extreme poverty rates and internal displacement (ca. 730.000 in 2021) (The World Bank Group, n.d., 2021). Many of the factors are remnants of historically developed dependencies due to colonization and exploitation for natural resources such as diamonds, gold and wood (IPCC, 2022; UNDP, 2019).

Additionally to these socio-economic factors ecosystems that are closely related to health and health system preparedness are vulnerable, too. Unstable water security and quality, food insecurities, heavy dependence on rainfed agriculture as well as forestry are under constant threats of short and long term climate change impacts in the form of floods, droughts or overall temperature increases (Baoro et al., 2018; Kamba et al., 2016; The World Bank Group, 2021). The combination of socio-economic factors and vulnerability of the ecosystem place the vast majority of people in highly vulnerable conditions with little capacity to face their vulnerabilities and future climate change impact. This poses a constant form of health stress on the health system.

The Health system itself, is moreover struggling with providing adequate health care to the public already and faces other forms of heat stress and shocks arising from communicable and non-communicable diseases. The most prevalent communicable diseases are malaria and diarrheal diseases which are also highly vulnerable to climate change (IPCC, 2022; The World Bank Group, 2021; World Health Organization, 2015). Other, non communicable diseases include high blood pressure and diabetes, of which the latter might increase the vulnerability of individuals towards for example extreme temperatures (The World Bank Group, 2021; Zilbermint, 2020). The health system in CAR is overloaded and on the verge of deteriorating due to limited capacity, staff availability (often because of conflict), limited medicine supplies, poor coordination between health services and under-financing (World Health Organization, 2016a). Additionally, the knowledge on climate change related health threats among health workers is limited or disrupted (The World Bank Group, 2021).

This results in a low health system preparedness level, and decreases the capacity to face climate change vulnerability. More importantly the low health system preparedness is exacerbated by the low capacity to face climate change vulnerability resulting from other fields as this research shows.

Climate change health vulnerability and health system preparedness

As the association between the capacity to face climate change vulnerability and health system preparedness is clearly present, it is unexpected that the findings cannot support an association between the sub-indicator climate change health vulnerability and health system preparedness. Still, the crude analysis indicates that for every incremental 0.1 increase in climate change health vulnerability (scale 0 to 1), health system preparedness significantly decreases by 6.7 points on its scale.

As a reminder, the sub-indicator measures the projected change in the number of deaths from climate change-induced diseases, as well as the projected change of length of transmission season of vector-borne diseases. It also accounts for a country's slum populations and the dependence on external resources for health systems. In addition, medical staff and access to improved sanitation facilities are also considered.

The coexistence of higher climate change health vulnerability in countries with lower health system preparedness is undisputed, but might be a side effect due to other, stronger vulnerability factors as assessed through the confounders. This points towards a complex interconnectedness of different vulnerability characteristics present in a country that could influence each other in numerous ways. These interactive forces might result in an indistinguishable synergistic effect that could show a coexistence of higher climate change health vulnerability and decreased health system preparedness, without climate change health vulnerability in particular being the main or distinguishable factor.

This interpretation is partly confirmed through previous research findings for example on vector-borne disease transmissions. Overall exposure to higher temperatures contribute to an expansion of favorable transmission areas for vector-borne diseases like malaria, which grew by 39% in 2021 compared to a baseline from 1950. Moreover, the effect of climate change on ecosystems is not limited to geographical expansion, but includes faster growth of reproduction rates as observed for dengue, zika, and chikungunya viruses, which show increased reproduction by 13% in 2021 compared to 1950 (Romanello et al., 2021). This underlines a clear association of climate change and changed transmission time and areas of vector-borne disease. Nevertheless, especially the role of related climate change vulnerability factors seems to be unclear for researchers.

A literature review on climate change and vector-borne diseases, for example, finds consistent proof of the correlation of climate change and vector-borne diseases, however, the extent of correlation varied greatly, due to other vulnerability factors (Wu & Huang, 2022). Identified reasons were the interplay of vulnerability factors such as level of urbanization, water shortages, and population age for certain vector-borne diseases (Li & Zheng, 2019; Lowe et al., 2021; Zhang et al., 2018). Wu and Huang (2022) conclude that the compounding effects of vulnerability factors on vector-borne diseases are still unknown and that especially the role of social factors need to be understood to a greater extent to be able to exacerbate single factor relationships that help to explain correlation.

To underline this interpretation even further, the Central African Republic is also the second lowest in terms of climate change health vulnerability, and also suffers from vector-borne diseases such as malaria. In CAR the increase in overall temperature and precipitation shows first influences on transmission areas and duration of malaria carrying mosquito.While the transmission area increased, the actual transmission season actually decreased in part of the country from 10-12 to 7-9 months (Ruckstuhl et al., 2017). Given that CAR is facing so many other vulnerabilities, some of these might also influence the transmission areas or the duration of malaria, as well as other dimensions of the sub indicator such as slum population and displacement.

All of this shows that future research in the interplay and compound effects of different vulnerability factors is needed in order to fully understand the complex interrelations at hand.

Strengths and limitations

Besides the limitations arising from the individual indicators, this study falls victim to the key limitation of the ecological fallacy, meaning that no inference can be deducted from any results of the study and conclusions cannot be applied on an individual country level from the data aggregated. Despite limitations due to some of the characteristics of the indicators as outlined below, the study provides an in depth understanding of the relationship between climate change and health system preparedness considering both, the capacity to face climate change vulnerability and climate change impact. Additionally, this study adds to the limited literature on climate change and health system preparedness as a whole, while providing a starting point with a global trend analysis for future research.

Global Climate Risk Index

The Global Climate Risk Index strikes through its robust measurement of socio-economic impacts of climate change induced weather-related loss events by accounting for two economic and two fatality dimensions. This way the index accounts for primary and tertiary impacts of climate change, but neglects secondary impacts such as food or water scarcity. Furthermore, slowly progressing forms of climate change like glacier melting, acidification of the oceans, increasing temperature of the oceans or rising sea levels are not considered either (Eckstein et al., 2019). This is a strong limitation as many forms of impact are disregarded. Moreover, next to the economic measures, the only social measures are fatalities, but often climate change impacts bring about displacement, income or property loss rather than loss of life (Ebi et al., 2021; IPCC, 2022). The justification for excluding those measures is that the quality of the data as well as the coverage may vary across countries due to limited availability of measuring points or methods used for the data collection. Hence, fatalities and economic impacts have the most comparable dimensions on an international level (Eckstein et al., 2019). The name of the index might be misleading as risk could easily be associated with vulnerability, which is not considered in the index. From an ethical point of view, combining fatalities and economic impact in one index could be seen as problematic, as it suggests that the loss of human lives is comparable to losses in monetary terms. For future research purposes it would be helpful to have public access to the sub-indicators to use the fatality indicators for example in purely health related contexts.

ND-Gain Index

The ND-Gain Index is convincing with its comprehensiveness and by its key feature of accounting for a country's vulnerability to climate disruptions as well as its readiness for adaptation capacities. The sub-indicators are carefully chosen and reviewed by experts in the fields outside the index team, and constantly updated in light of new emerging evidence or data. Furthermore data is obtained from highly reliable sources and must adhere to internal standards to assure relevance and comparability (Chen et al., 2015). Following the argumentation from (Eckstein et al., 2019), the comparability might be questionable. Additionally, in the ND-gain missing values are estimated using linear interpolation, which might reduce the accuracy of values for individual countries, years or sub-indicators (Chen et al., 2015). Furthermore, some sub-indicators are based on estimates for future predictions which should always be seen in the light of the prediction model applied. Nevertheless, the ND-Gain index seems to be one of the most comprehensive climate change related indices with an overall high vulnerability due to careful data selection and expert screening. Future research could benefit if climate change impact measures for the different indicators were reliably available in a separate index to allow for comparison.

Health system preparedness

The SPAR score is particularly useful because it is available for each country and provides a high degree of comparability between countries, as it is based on indicating the implementation of international health regulations levels based on coherent definitions. One limitation, however, is that the score is based on countries' self evaluation, which could bias the data as countries may tend to indicate higher levels of IHR implementations. While the IHR explicitly restrain from limiting health system preparedness to specific diseases as to maintain their relevance and allow for flexibility, a particularly strong focus appears to lie on preparedness for outbreaks of communicable disease, and less for health emergencies related to, for example, natural disasters due to climate change (World Health Organization, 2016b, 2018). Additionally it should be noted that the role of equity in access to healthcare for the population is disregarded completely. As climate change is such a pressing global health issue, it should become a core element in international health regulations to hold countries accountable for implementing climate change preparedness in their health systems.

Conclusion

Climate change is the most demanding and urgent global challenge humanity faces in the 21st century. This study adds to the research gap on the relationship between climate change and health system preparedness by scrutinizing progress in health system preparedness as a whole, globally in relation to two distinct exposures: the acute capacity to face climate change vulnerability
and prior climate change impact. The results of this study are twofold: on the one hand, health systems do not seem to increase their preparedness after being impacted by climate change, even after 5 years. On the other hand, the results suggest that countries that are low in capacity to face climate change vulnerability tend to be also those that have the least prepared health system. This is a concerning development as vulnerable countries are more likely to be impacted by future climate change and more severely. In order to prevent severe adverse health impacts arising from climate change, health systems need to incorporate climate change preparedness in their health systems internationally and legally binding. Therefore future global policies should focus on adapting the international health regulations by the WHO for example guided by the WHO framework for climate-prepared health systems from 2015. Additional research should assess how implementation can be feasible and effective, especially in low-income countries, and how to reduce climate change vulnerability.

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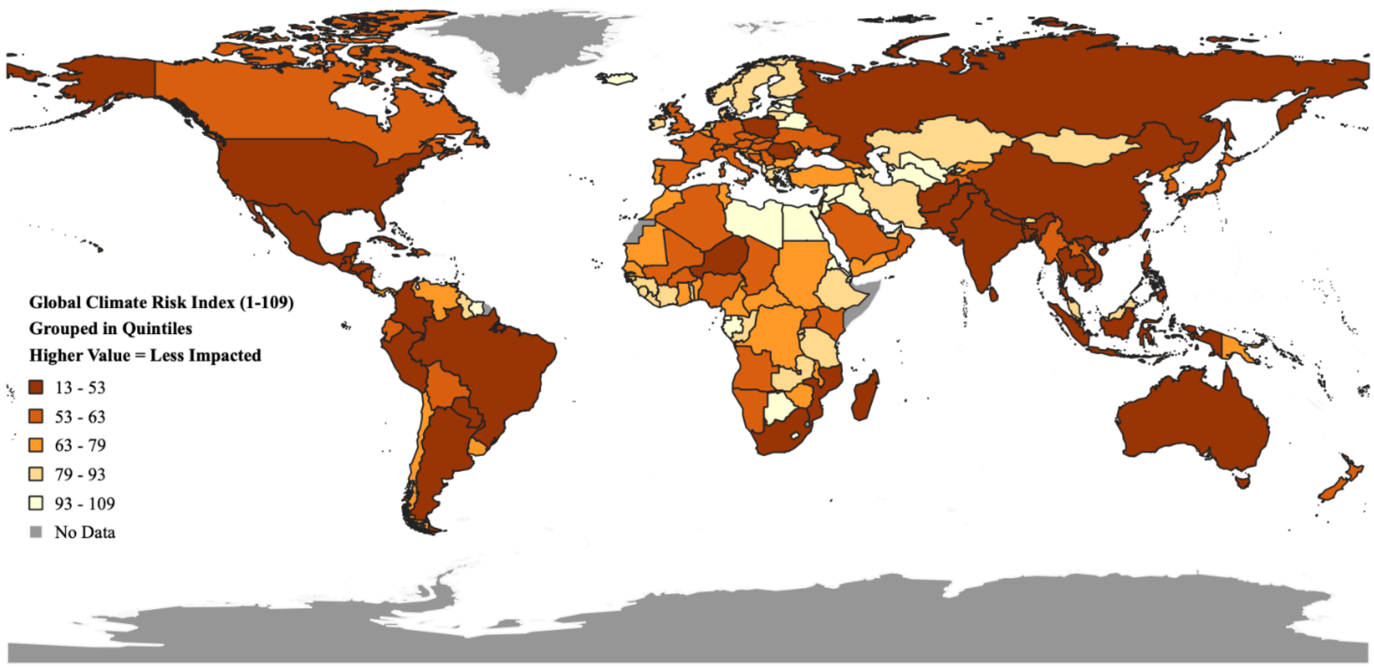
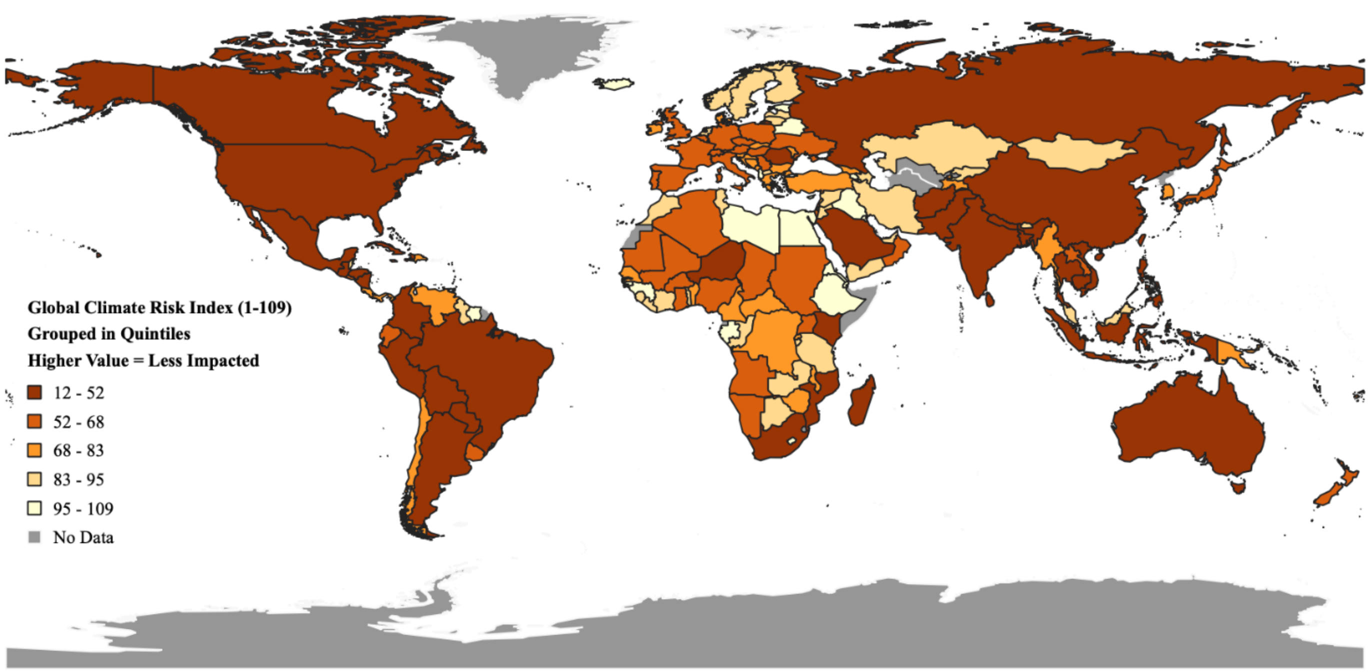
Appendix

Maps

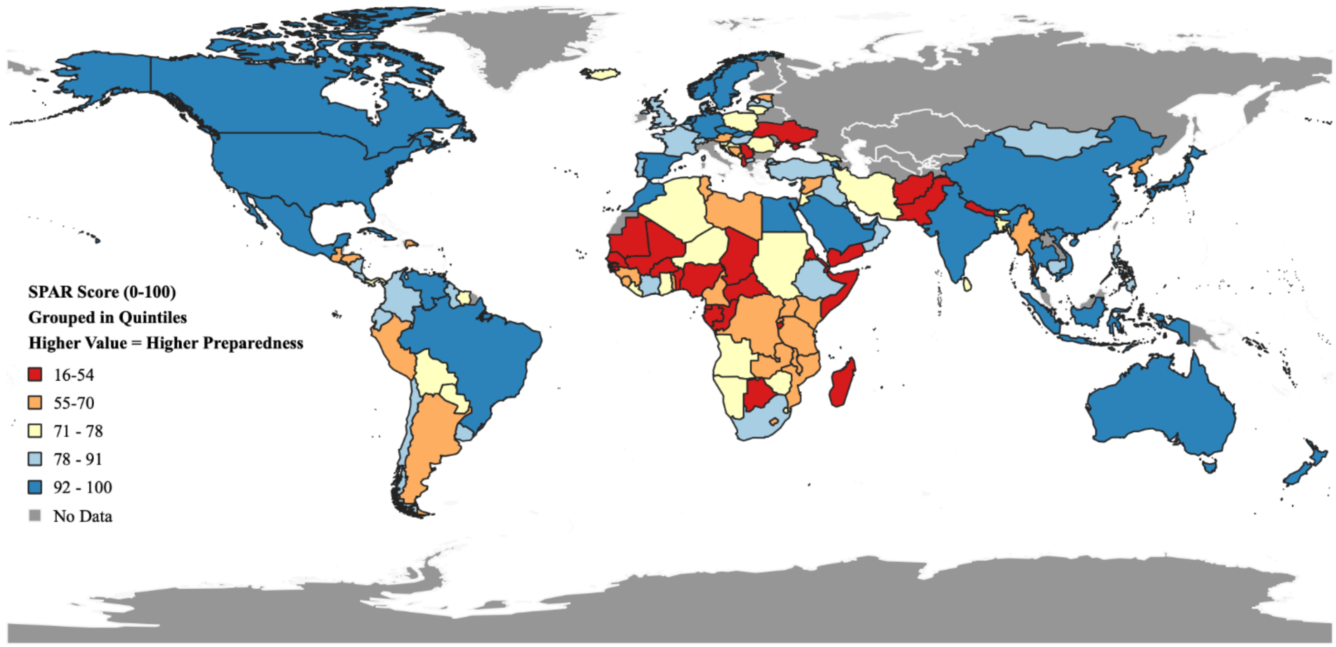
Climate change impact 2008-2012



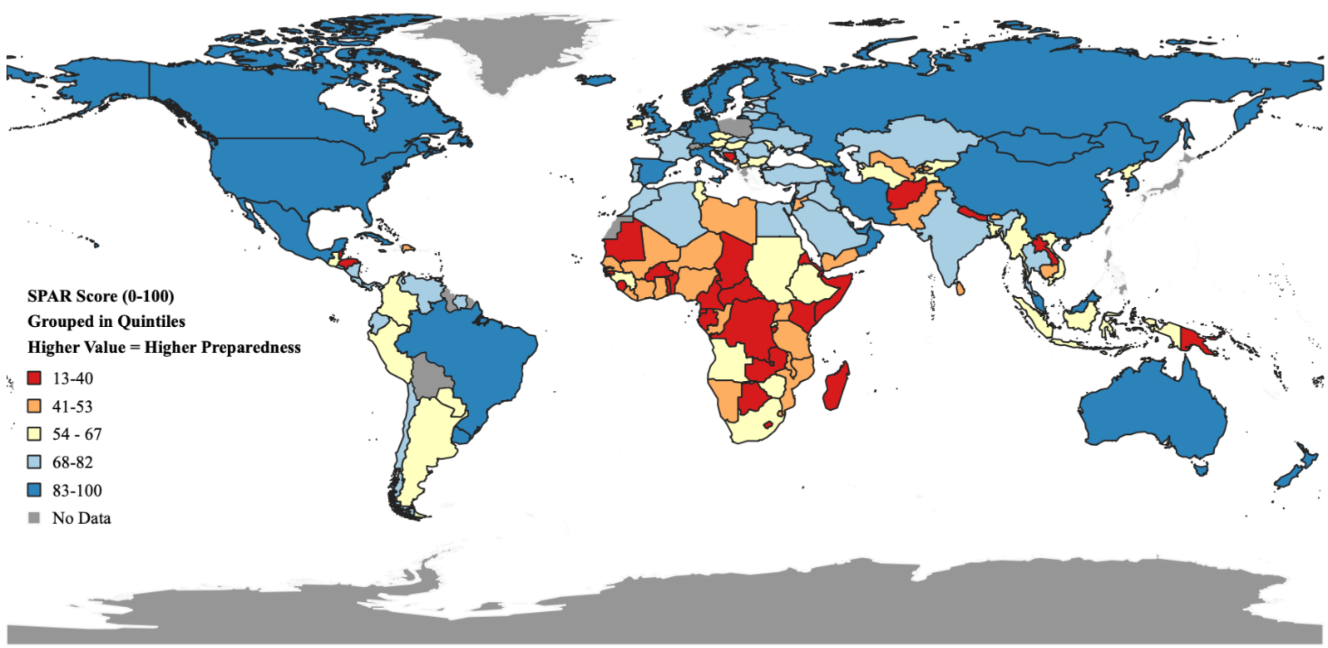
Climate change impact 2009-2013



Health system preparedness 2017

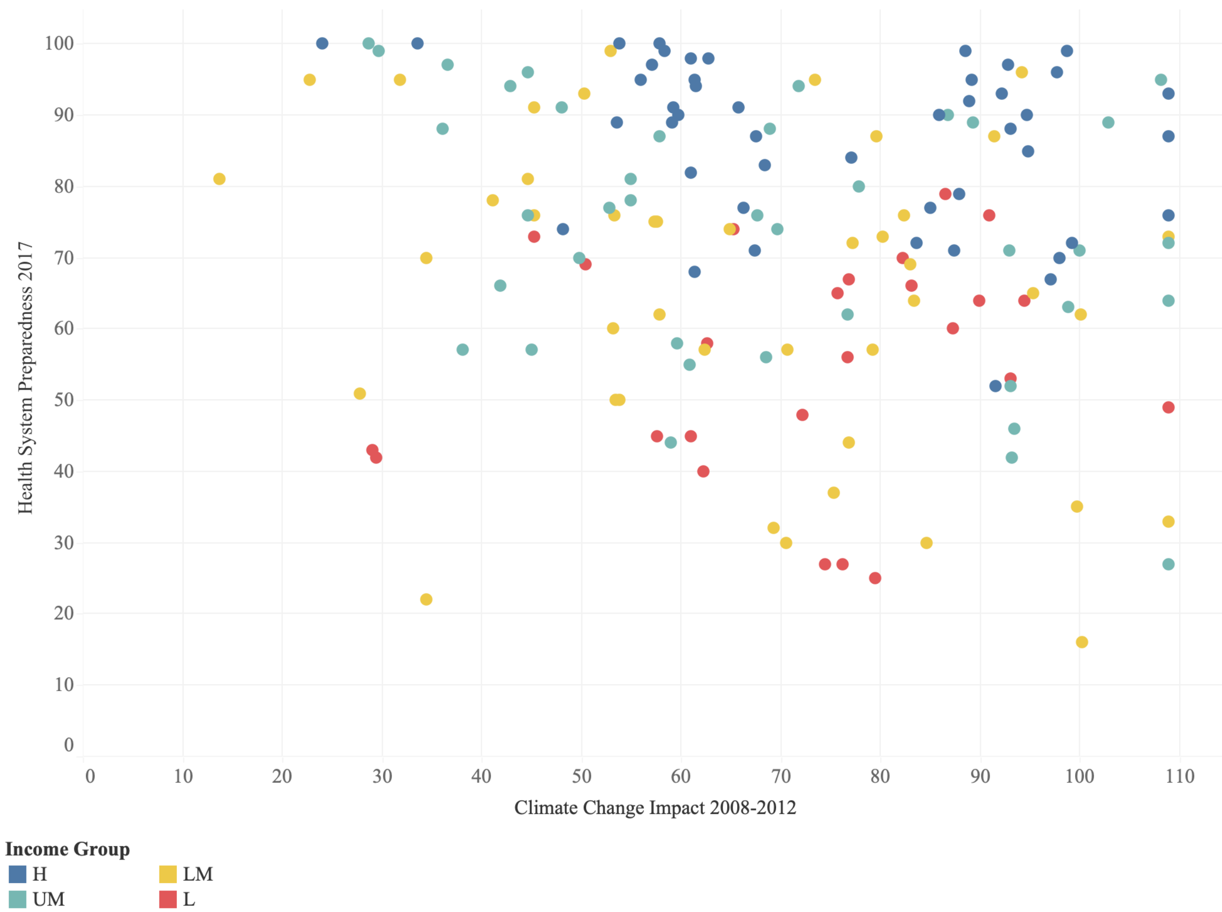


Health system preparedness 2018

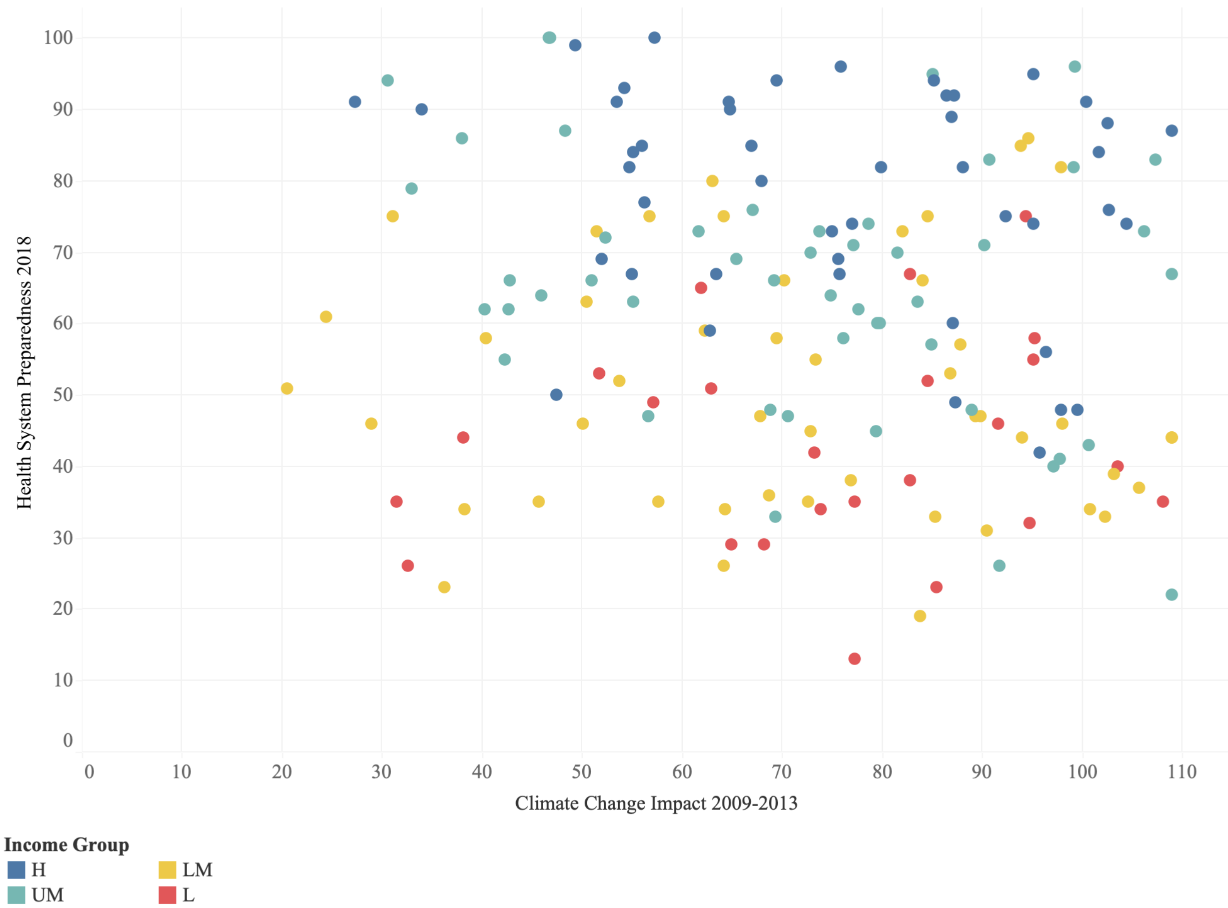


Scatterplots

Climate change impact 2008-2012 and health system preparedness 2017, color coded per income group



Climate change impact 2009-2013 and health system preparedness 2017, color coded per income group



Correlation matrices

Confounders for averages 2008-2012

Variable	Share of population above 65 in 08-12	General government gross debt as % of GDP 08-12	Global Peace Index 08-12	Human Development Index 08-12
Share of population above 65 in 08-12	1.00			
General government gross debt as % of GDP 08-12	0.36	1.00		
Global Peace Index 08-12	-0.49	-0.10	1.00	
Human Development Index 08-12	0.72	0.21	-0.54	1.00

Confounders for averages 2009-2013

Variable	Share of population above 65 in 09-13	General government gross debt as % of GDP 09-13	Global Peace Index 09-13	Human Development Index 09-13
Share of population above 65 in 09-13	1.00			
General government gross debt as % of GDP 09-13	0.42	1.00		
Global Peace Index 09-13	-0.50	-0.16	1.00	
Human Development Index 09-13	0.73	0.27	-0.54	1.00

Confounders for averages 2010-2014

Variable	Share of population above 65 in 10-14	General government gross debt as % of GDP 10-14	Global Peace Index 10-14	Human Development Index 10-14
Share of population above 65 in 10-14	1.00			
General government gross debt as % of GDP 10-14	0.46	1.00		
Global Peace Index 10-14	-0.51	-0.20	1.00	
Human Development Index 10-14	0.73	0.29	-0.54	1.00

Confounders for 2017

Variable	Share of population above 65 in 17	General government gross debt as % of GDP 17	Global Peace Index 17	Human Development Index 17
Share of population above 65 in 17	1.00			
General government gross debt as % of GDP 17	0.31	1.00		
Global Peace Index 17	-0.52	-0.07	1.00	
Human Development Index 17	0.75	0.12	-0.55	1.00

Confounders for 2018

Variable	Share of population above 65 in 18	General government gross debt as % of GDP 18	Global Peace Index 18	Human Development Index 18
Share of population above 65 in 18	1.00			
General government gross debt as % of GDP 18	0.25	1.00		
Global Peace Index 18	-0.53	-0.03	1.00	
Human Development Index 18	0.76	0.09	-0.55	1.00

Confounders for 2019

Variable	Share of population above 65 in 19	General government gross debt as % of GDP 19	Global Peace Index 19	Human Development Index 19
Share of population above 65 in 19	1.00			
General government gross debt as % of GDP 19	0.19	1.00		
Global Peace Index 19	-0.53	-0.01	1.00	
Human Development Index 19	0.76	0.057	-0.56	1.00